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Coastal Inlets Research Program

STWAVE: Steady-State Spectral Wave Model

Report 1
User's Manual for STWAVE Version 2.0

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WES

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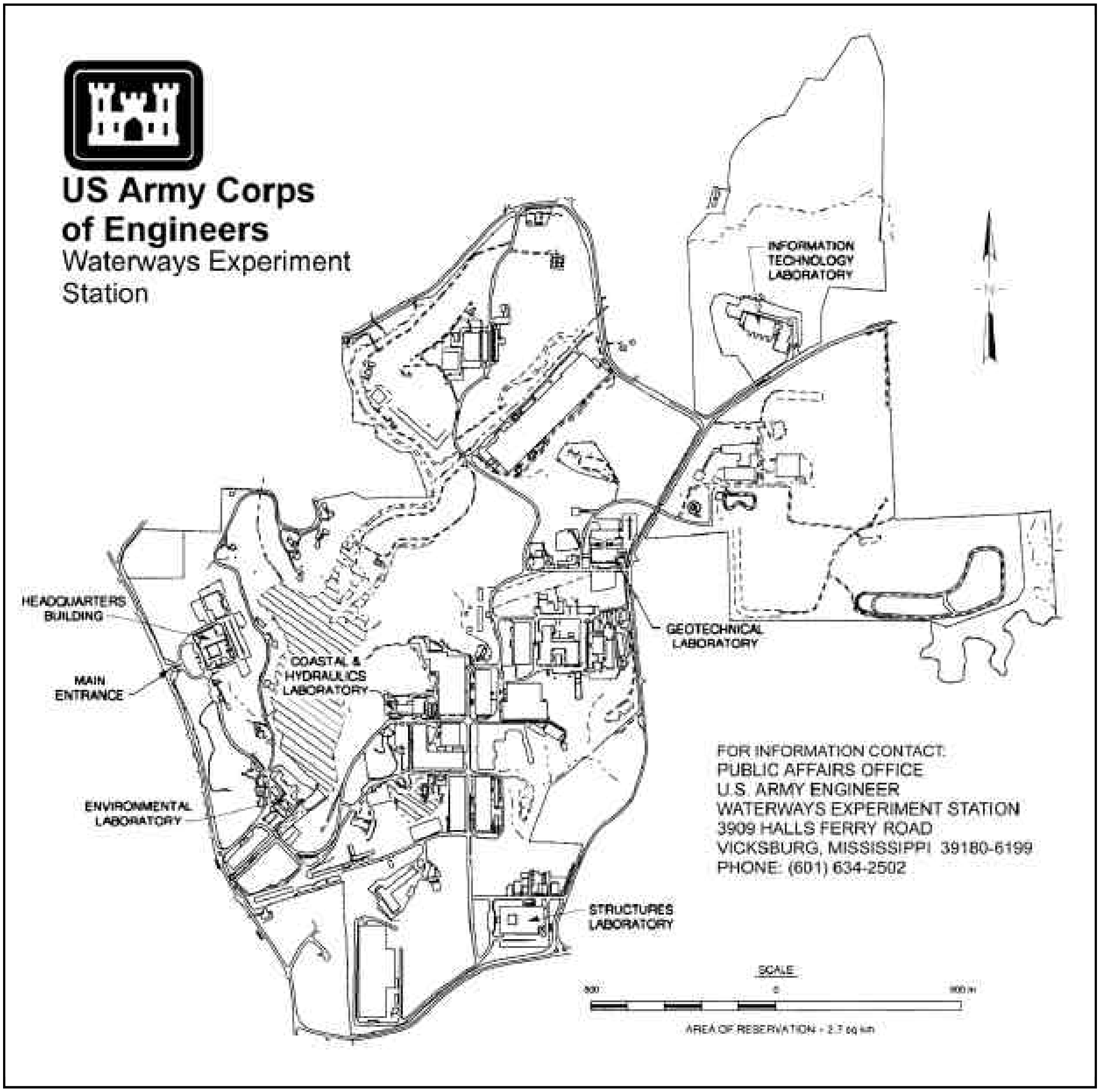

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Preface

The work described herein was conducted at the U.S. Army Engineer Waterways Experiment Station (WES), Coastal and Hydraulics Laboratory (CHL) as part of the Coastal Inlets Research Program (CIRP) under the work unit Modeling Waves at Inlets. Overall program management for CIRP is directed by the Hydraulic Design Section of the Headquarters, U.S. Army Corps of Engineers (HQUSACE). Program Monitors for the CIRP are Messrs. Barry W. Holliday, John Bianco, and Charles B. Chesnutt, HQUSACE. The Program Manager is Mr. E. Clark McNair, CHL, and CIRP Technical Manager is Dr. Nicholas C. Kraus, CHL.

The purpose of the Modeling Waves at Inlets work unit is to provide field tools for quantifying wave processes at coastal inlets. Wave information is required for almost all engineering studies near inlets to estimate channel shoaling and migration, shoreline change, scour, forces on structures, and navigation safety. This report documents a "workhorse" numerical model for estimating nearshore wave growth and transformation. The purpose of the report is to transfer this technology to field users, through guidance on model application.

This study was conducted by CHL personnel under the general direction of Dr. James R. Houston, Director, and Mr. Charles C. Calhoun, Jr. (retired), Assistant Director. Direct guidance was provided by Messrs. Thomas W. Richardson, Chief, Coastal Sediments and Engineering Division, and Mr. Bruce A. Ebersole, Chief, Coastal Processes Branch (CPB). This report was prepared by Drs. Jane McKee Smith, CPB, and Donald T. Resio, Senior Research Scientist, CHL, and Dr. Alan K. Zundel, Engineering Computer Graphics Laboratory, Brigham Young University. Assistance and review were provided by Mr. S. Jarrell Smith, CPB, Dr. Joon P. Rhee, Prototype Measurement and Analysis Branch, and Ms. Lori Hadley, Coastal Hydrodynamics Branch.

At the time of publication of this report, Acting Director of WES was COL Robin R. Cababa, EN.

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1 Introduction

Estimating nearshore wind-wave growth and transformation is a critical component of most coastal engineering projects, e.g., predicting bathymetric and shoreline change, estimating navigation channel shoaling and migration, designing or repairing coastal structures, assessing navigation conditions, and evaluating natural evolution of coastal inlets or beaches versus consequences of engineering actions. Nearshore wave propagation is influenced by complex bathymetry (including shoals and navigation channels); tide-, wind-, and wave-generated currents; tide- and surge-induced water-level variation; and coastal structures. Use of numerical wave models has become widespread to represent wave transformation primarily because of their increasing sophistication and economy of application relative to the large expense of field measurements or physical model studies.

This report describes the application of the steady-state spectral wave model, STWAVE. The purpose of STWAVE is to provide an easy-to-apply, flexible, and robust model for nearshore wind-wave growth and propagation. Recent upgrades to the model include wave-current interaction and steepness-induced wave breaking. STWAVE has also been incorporated into the Surface-Water Modeling System (SMS), which provides a user interface and supporting software for grid generation, interpolation of current fields, generation of input spectra, and visualization of model output.

This report describes procedures for using STWAVE. In Chapter 2, an overview of the model governing equation and the numerical discretization is presented. In Chapter 3, the necessary input files are described. Guidelines for selecting parameter values are also given. In Chapter 4, the content and format of the STWAVE output files are described. Chapter 5 gives a tutorial on SMS application. Chapter 6 provides two example applications of the model for wave growth and transformation over simple bathymetry and wave transformation over complex bathymetry with wave-current interaction. Sample input files are given in Appendixes A-D.

2 Governing Equations and Numerical Discretization

This chapter gives an overview of the phase-averaged spectral wave model STWAVE (STeady-state spectral WAVE model) (Resio 1987, 1988a, 1988b; Davis 1992). STWAVE is a steady-state finite-difference model based on the wave action balance equation. This report describes STWAVE version 2.0, which includes the addition of wave-current interaction.

Model Capabilities

The purpose of applying nearshore wave transformation models is to describe quantitatively the change in wave parameters (wave height, period, direction, and spectral shape) between the offshore and the nearshore (typically depths of 20 m or less). In relatively deep water, the wave field is fairly homogeneous on the scale of kilometers; but in the nearshore, where waves are strongly influenced by variations in bathymetry, water level, and current, wave parameters may vary significantly on the scale of tens of meters. Offshore wave information is typically available from a wave gauge or a global- or regional-scale wave hindcast or forecast. Nearshore wave information is required for the design of almost all coastal engineering projects. Waves drive sediment transport and nearshore currents, induce wave setup and runup, excite harbor oscillations, or impact coastal structures. The longshore and cross-shore gradients in wave height and direction can be as important as the magnitude of these parameters for some coastal design problems.

STWAVE simulates depth-induced wave refraction and shoaling, current-induced refraction and shoaling, depth- and steepness-induced wave breaking, diffraction, wave growth because of wind input, and wave-wave interaction and white capping that redistribute and dissipate energy in a growing wave field.

A wave spectrum is a statistical representation of a wave field. Conceptually, a spectrum is a linear superposition of monochromatic waves. A spectrum describes the distribution of wave energy as a function of frequency (one-

dimensional spectrum) or frequency and direction (two-dimensional spectrum). An example of a one-dimensional wave spectrum is given in Figure 1. The peak period of the spectrum is the reciprocal of the frequency of the peak of the spectrum. The wave height (significant or zero-moment wave height) is equal to four times the area under the spectrum. For the example spectrum given in Figure 1, the peak frequency is 0.105 Hz, the peak period is 9.5 sec, and the wave height is 2.8 m. STWAVE is based on the assumption that the relative phases of the spectral components are random, and thus phase information is not tracked (i.e., it is a phase-averaged model). In practical applications, wave phase information throughout a model domain is rarely known accurately enough to initiate a phase-resolving model. Typically, wave phase information is only required to resolve wave-height variations near coastal structures for detailed, near-field reflection and diffraction patterns. Thus, for these situations, a phase-resolving model should be applied.

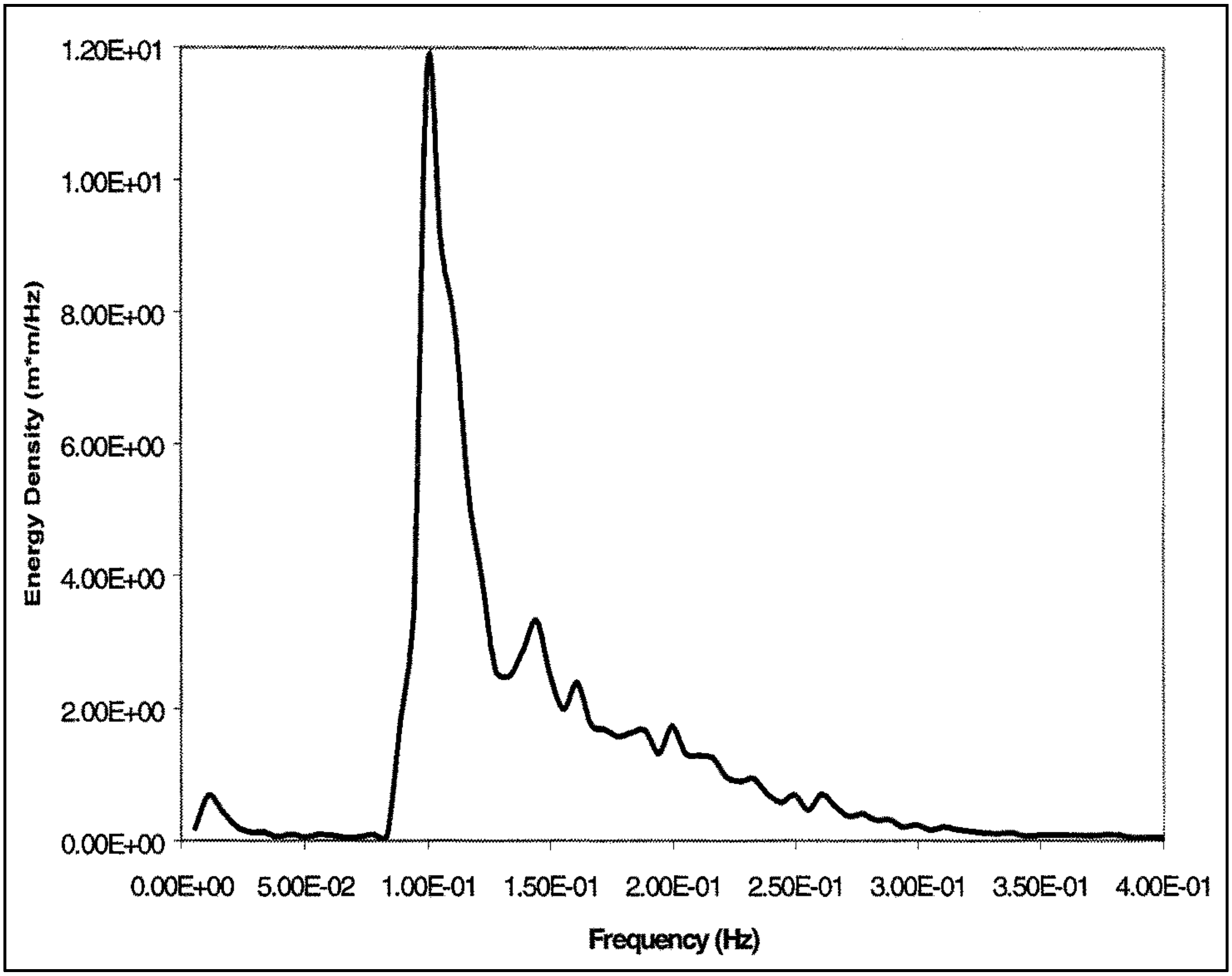

Figure 1. Sample one-dimensional wave spectrum

Model Assumptions

The assumptions made in STWAVE version 2.0 are as follows:

a. *Mild bottom slope and negligible wave reflection*. STWAVE is a half-plane model, meaning that wave energy can propagate only from the off-shore toward the nearshore (±87.5 deg from the x axis of the grid, which is typically the approximate shore-normal direction). Waves reflected from the shoreline or from steep bottom features travel in directions outside this half plane and thus are neglected. Forward-scattered waves, e.g., waves reflected off a structure but traveling in the $+x$ direction, are also neglected.

b. *Spatially homogeneous offshore wave conditions*. The variation in the wave spectrum along the offshore boundary of a modeling domain is rarely known, and for domains on the order of tens of kilometers, is expected to be small. Thus, the input spectrum in STWAVE is constant along the offshore boundary. Future versions of the model may allow variable input.

c. *Steady-state waves, currents, and winds*. STWAVE is formulated as a steady-state model. A steady-state formulation reduces computation time and is appropriate for wave conditions that vary more slowly than the time it takes for waves to transit the computational grid. For wave generation, the steady-state assumption means that the winds have remained steady sufficiently long for the waves to attain fetch-limited or fully developed conditions (waves are not limited by the duration of the winds).

d. *Linear refraction and shoaling*. STWAVE incorporates only linear wave refraction and shoaling, thus does not represent wave asymmetry. Model accuracy is therefore reduced at large Ursell numbers (wave heights are underestimated).

e. *Depth-uniform current*. The wave-current interaction in the model is based on a current that is constant through the water column. If strong vertical gradients in current occur, their modification of refraction and shoaling is not represented in the model. For most applications, three-dimensional current fields are not available.

f. *Bottom friction is neglected*. The significance of bottom friction on wave dissipation has been a topic of debate in wave modeling literature. Bottom friction has often been applied as a tuning coefficient to bring model results into alignment with measurements. Although bottom friction is easy to apply in a wave model, determining the proper friction coeffi-cients is difficult. Also, propagation distances in a nearshore model are relatively short (tens of kilometers), so that the cumulative bottom friction dissipation is small. For these reasons, bottom friction is neglected in STWAVE.

Ongoing research will enhance present model capabilities and eliminate some model assumptions. The following sections describe wave propagation and source/sink terms in STWAVE version 2.0.

Governing Equations

Interaction of waves with currents is considered in a reference frame moving with the current. Wave parameters in this frame are denoted with the subscript *r*, for being "relative" to the current, and parameters in the nonmoving reference frame are subscripted *a*, for "absolute." The wave dispersion relationship is given in the moving reference frame as (Jonsson 1990 and others)

$$\omega_r^2 = gk \tanh kd \tag{1}$$

where

T = angular frequency

g = gravitational acceleration

k = wave number

d = water depth

In the absolute frame of reference, the dispersion equation is

$$\omega_a = \omega_r + kU \cos(\delta - \alpha) \tag{2}$$

where

U = current speed

* = direction of current relative to a reference frame (the x axis, here)

″ = wave orthogonal direction (normal to the wave crest) (Figure 2)

The wave number is solved by substituting Equation 1 into Equation 2 and iteratively solving for k. The wave number and wavelength (L=(2*B*)/k) are the same in both reference frames.

Solutions for refraction and shoaling also require wave celerities, C, and group celerities, C_g, in both reference frames. In the reference frame relative to the current,

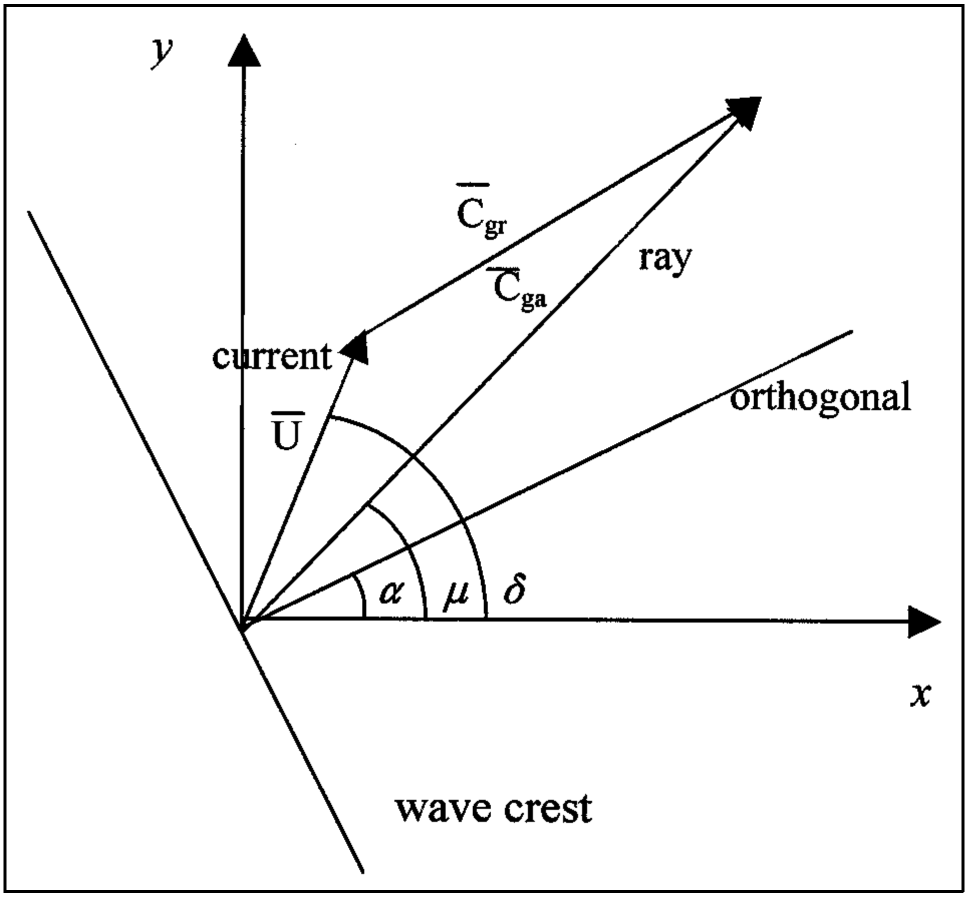

Figure 2. Definition sketch of wave and current vectors

$$C_r = \frac{\omega_r}{k} \tag{3}$$

$$C_{gr} = 0.5\,C_r\left(1 + \frac{2kd}{\sinh\ 2kd}\right) \tag{4}$$

The direction of both the relative celerity and group celerity is ", the wave orthogonal direction. In the absolute reference frame,

$$C_a = C_r + U\cos\left(\delta - \alpha\right) \tag{5}$$

$$\left(C_{ga}\right)_i = \left(C_{gr}\right)_i + \left(U\right)_i \tag{6}$$

where i subscript is tensor notation for the x and y components. The direction of the absolute celerity is also in the wave orthogonal direction. The absolute group celerity defines the direction of the wave ray, so the wave ray direction (Figure 2) is defined as

$$\mu = \tan^{-1}\left(\frac{C_{gr}\ \sin\ \alpha + U\ \sin\ \delta}{C_{gr}\ \cos\ \alpha + U\ \cos\ \delta}\right) \tag{7}$$

The distinction between the wave orthogonal (direction perpendicular to the wave crest) and the wave ray (direction of energy propagation) is important in describing wave-current interaction. Without currents, the wave rays and orthogonals are the same, but with currents, the wave energy moves along the rays whereas the wave direction is defined by the orthogonals.

The wave orthogonal direction for steady-state conditions is given by (Mei 1989; Jonsson 1990)

$$C_{ga}\ \frac{D\alpha}{DR} = -\ \frac{C_r k}{\sinh\ 2kd}\ \frac{Dd}{Dn} - \frac{k_i}{k}\ \frac{DU_i}{Dn} \tag{8}$$

where D is a derivative, R is a coordinate in the direction of the wave ray, and n is a coordinate normal to the wave orthogonal.

The governing equation for steady-state conservation of spectral wave action along a wave ray is given by (Jonsson 1990):

$$(C_{ga})_i\ \frac{\partial}{\partial x_i}\ \frac{C_a\ C_{ga}\ \cos(\mu - \alpha)E}{w_r} = \Sigma\frac{S}{w_r} \tag{9}$$

where

E = wave energy density spectrum (which is a function absolute angular frequency w_a and direction θ)

S = energy source and sink terms

Refraction and shoaling

Refraction and shoaling are implemented in STWAVE by applying the conservation of wave action along backward traced wave rays. Rays are traced in a piecewise manner, from one grid column to the next. The two-dimensional wave spectra are set as input along the first grid column (the offshore boundary). For a point on the second grid column, the spectrum is calculated by back tracing a ray for each frequency and direction component of the spectrum. The ray dir-ection, *F*, is determined by Equation 7. Only ray directions propagating toward the shore (-87.5 to +87.5 deg) are included. Energy propagating toward the offshore is neglected.

The wave ray is traced back to the previous grid column, and the length of the ray segment *DR* is calculated. Derivatives of depth and current components normal to the wave orthogonal are estimated (based on the orthogonal direction at column 2) and substituted into Equation 8 to calculate the wave orthogonal direction at column 1. Then, the wave number, wave and group celerities, and ray angle in the previous column are calculated. The energy is calculated as a weighted average of energy between the two adjacent grid points in the column and the direction bins. The energy density is corrected by a factor that is the ratio of the 5-deg standard angle band width to the width of the back-traced band to account for the different angle increment in the back-traced ray. The shoaled and refracted wave energy in column 2 is then calculated from the conservation of wave action along a ray (Equation 9).

In a strong opposing current (e.g., ebb currents at an inlet), waves may be blocked by the current. Blocking occurs if there is no solution to the dispersion equation (Equation 2). Or, to state it another way, blocking occurs if the relative wave group celerity is smaller than the magnitude of the opposing current, so wave energy cannot propagate against the current. In deep water, blocking occurs for an opposing current with magnitude greater than one-fourth the deepwater wave celerity without current ($0.25\, g\, T_a/(2\pi)$, where T_a is the absolute wave period). If blocking occurs, the wave energy is dissipated through breaking.

Diffraction

Diffraction is included in STWAVE in a simple manner through smoothing of wave energy. The model smooths energy in a given frequency and direction band using the following form

$$E_j(w_a, \theta) = 0.55 E_j(w_a, \theta) + 0.225 \left(E_{j+1}(w_a, \theta) + E_{j-1}(w_a, \theta) \right) \tag{10}$$

where E is the energy density in a given frequency and direction band, and the subscript j indicates the grid row index (alongshore position). Equation 10 provides smoothing of strong gradients in wave height that occur in shelter regions, but provides no turning of the waves. This formulation is grid-spacing dependent, which is a serious weakness. Efforts are ongoing to implement a more rigorous diffraction representation.

Source/sink terms

Surf-zone wave breaking. The wave-breaking criterion applied in the first version of STWAVE was a function of the ratio of wave height to water depth

$$\frac{H_{mo_{\max}}}{d} = 0.64 \tag{11}$$

where H_{mo} is the energy-based zero-moment wave height. At an inlet, where waves steepen because of the wave-current interaction, wave breaking is enhanced because of the increased steepening. Smith, Resio, and Vincent (1997) performed laboratory measurements of irregular wave breaking on ebb currents and found that a breaking relationship in the form of the Miche criterion (1951) was simple, robust, and accurate

$$H_{mo_{\max}} = 0.1L \tanh kd \tag{12}$$

(see also Battjes 1982 and Battjes and Janssen 1978). Equation 12 is applied in version 2.0 of STWAVE as a maximum limit on the zero-moment wave height. The energy in the spectrum is reduced at each frequency and direction in proportion to the amount of prebreaking energy in frequency and direction band. Nonlinear transfers of energy to high frequencies that occur during breaking are not represented in the model.

Wind input. Waves grow through the transfer of momentum from the wind field to the wave field. The flux of energy, F_{in}, into the wave field in STWAVE is given by (Resio 1988a)

$$F_{in} = \lambda \frac{\rho_a}{\rho_w} 0.85 C_m \frac{u_*^2}{g} \tag{13}$$

where

λ = partitioning coefficient that represents percentage of total atmosphere to water momentum transfer that goes directly into wave field (0.75)

ρ_a = density of air

ρ_w = density of water

C_m = mean wave celerity

u_* = friction velocity (equal to product of wind speed, U, and square root of drag coefficient, C_D = .0012+.000025U)

In deep water, STWAVE provides a total energy growth rate that is consistent with Hasselmann et al. (1973).

The energy gain to the spectrum is calculated by multiplying the energy flux by the equivalent time for the wave to travel across a grid cell

$$\Delta t = \frac{\Delta x}{\beta \overline{C}_g \cos \theta_m} \tag{14}$$

where

Δt = equivalent travel time

Δx = grid spacing

β = factor equal to 0.9 for wind seas

$\bar{C}_g$ = average group celerity of spectrum

θ_m = mean wave direction, relative to grid

Because STWAVE is a half-plane model, only winds blowing toward the shore ($+x$ direction) are included. Wave damping by offshore winds and growth of offshore-traveling waves are neglected.

Wave-wave interaction and white capping. As energy is fed into the waves from the wind, it is redistributed through nonlinear wave-wave interaction. Energy is transferred from the peak of the spectrum to lower frequencies (decreasing the peak frequency or increasing the peak period) and to high frequencies (where it is dissipated).

In STWAVE, the frequency of the spectral peak is allowed to increase with fetch (or equivalently propagation time across a fetch). The equation for this rate of change of f_p is given by

$$(f_p)_{i+1} = \left[(f_p)_i^{7/3} - \frac{9}{5} \zeta \left(\frac{u_*}{g} \right)^{4/3} \Delta t \right]^{-3/7} \tag{15}$$

where the i and i+1 subscripts refer to the grid column indices within STWAVE and ζ is a dimensionless constant (Resio and Perrie 1989). The energy gained by the spectrum is distributed within frequencies on the forward face of the spec-trum (frequencies lower than the peak frequency) in a manner that retains the self-similar shape of the spectrum.

Wave energy is dissipated (most notably in an actively growing wave field) through energy transferred to high frequencies and dissipated through wave breaking (white capping) and turbulent/viscous effects. There is a dynamic balance between energy entering the wave field because of wind input and energy leaving the wave field because of nonlinear fluxes to higher frequencies (Resio 1987, 1988a). The energy flux to high frequencies is represented in STWAVE as

$$\Gamma_E = \frac{\epsilon g^{1/2} E^3 k_p^{9/2}}{\tanh^{3/4} (k_p d)} \tag{16}$$

where

$'_E$ = energy flux

ϵ = coefficient equal to 30

E = total energy in spectrum

k_p = wave number associated with peak of spectrum (Resio 1987)

The energy loss to the spectrum is calculated by multiplying the energy flux by the equivalent time for the wave to travel across a grid cell (Δt) with β equal to 1.0 for the swell portion of the spectrum and 0.9 for the sea portion of the spectrum. This dissipation is only applied in the model if wind input is included.

Numerical Discretization

STWAVE is a finite-difference numerical model, formulated on a Cartesian grid. Grid cells are square (Δx =) *y*). Variable grid resolution can be obtained by nesting model runs. This is accomplished by running the model at a coarse resolution and saving a spectrum at a nearshore point. This nearshore spectrum can then be used as a boundary condition for another grid of finer resolution. A schematic of a grid is shown in Figure 3. STWAVE operates in a local coordinate system, with the x axis oriented in the cross-shore direction (origin offshore) and the y axis oriented alongshore, forming a right-handed coordinate system. The orientation of the x axis (±87.5 deg) defines the half plane that is represented in the model. The y axis is typically aligned with the bottom contours. Wave angles are defined in a mathematical sense, measured counterclockwise from the x axis.

Lateral boundaries in the model can be specified as land or water by specifying the cell depths as positive (water) or negative (land). Note that specifying land around the entire grid will give different results than if the lateral boundaries are water. Land boundaries reduce wave growth near the boundary because they “block” propagation from landward directions. If the boundaries are specified as water, a zero-gradient type of boundary is applied that allows energy, consistent with neighboring cells, to propagate into or out of the domain along the lateral boundary.

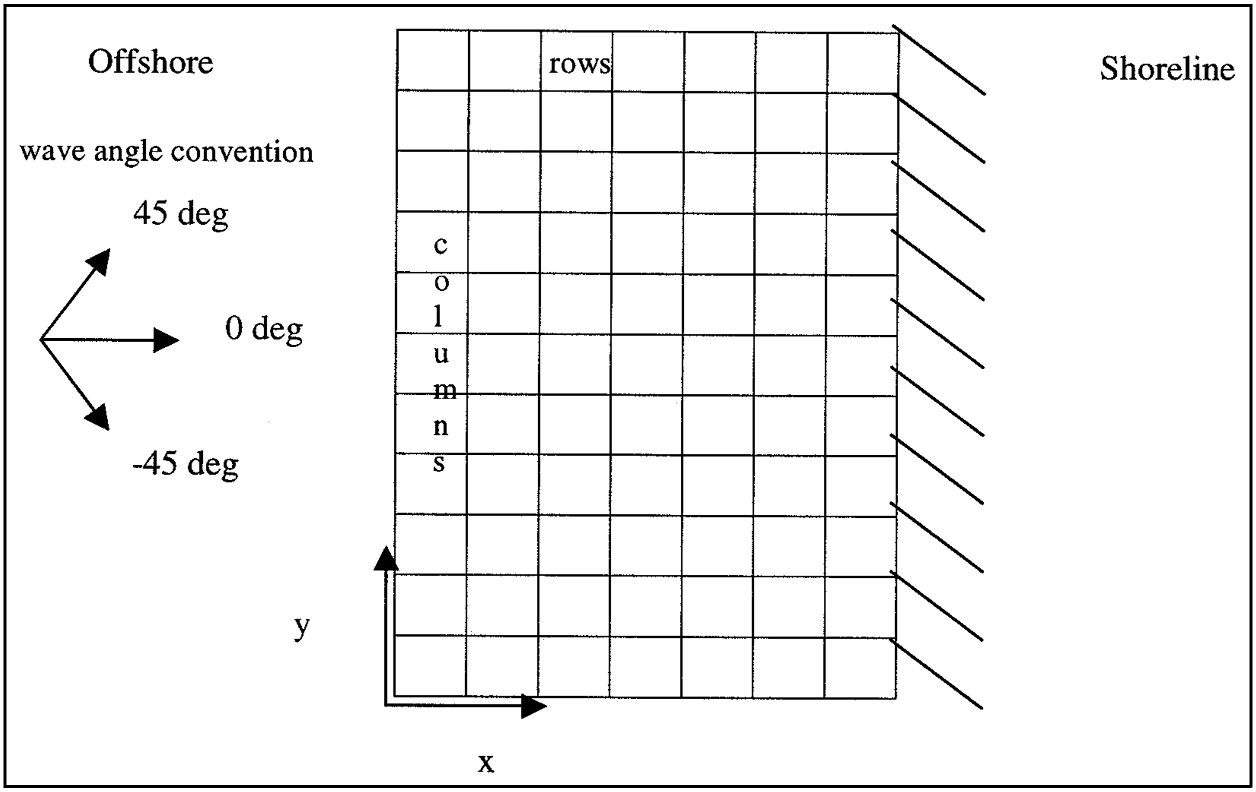

Figure 3. Schematic of STWAVE grid

3 Input File Description

STWAVE has four input files. These files specify model parameters, bathymetry, incident wave spectra, and current fields. The current field file is optional and required only if the wave-current interaction is specified. The other three files are always required. The input files are most easily generated using the SMS interface discussed in Chapter 5, but may also be generated using an editor or other programs. File formats for the input files must remain the same, regardless of how the files are generated. Parameter names starting with “N” or “I” indicate integer parameter values are required. All other names indicate real parameter values. A schematic of the STWAVE input and output files is given in Figure 4.

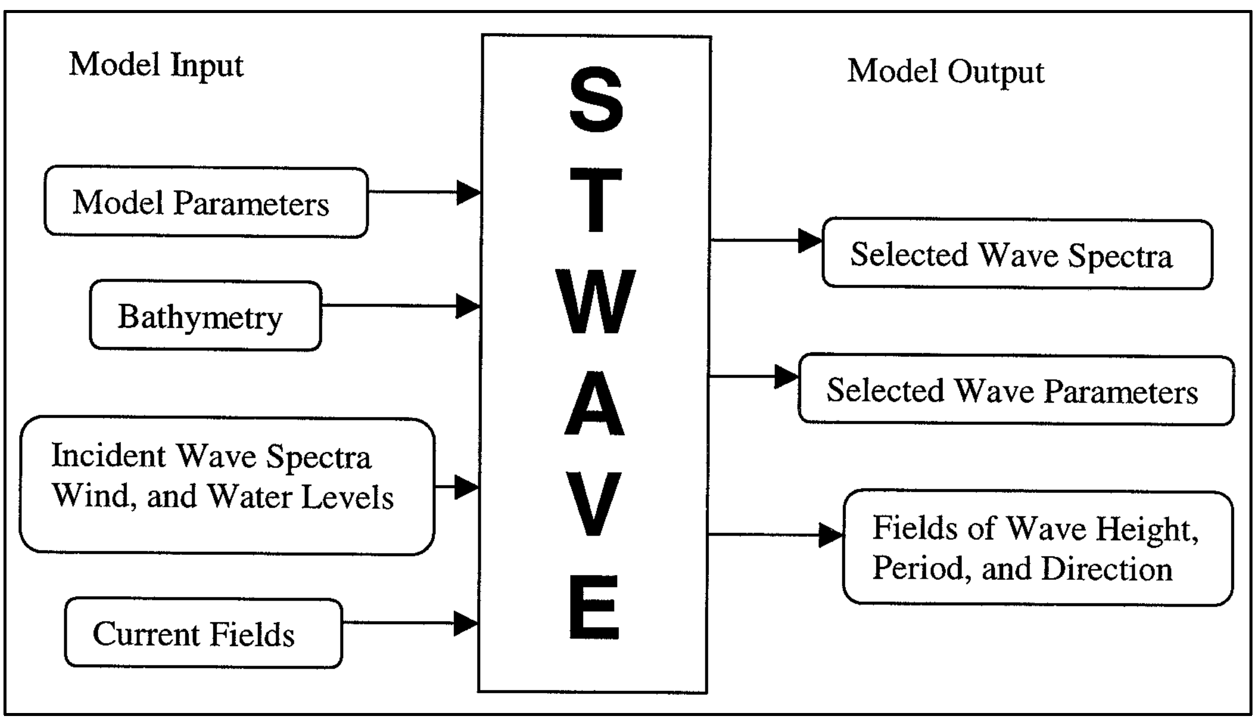

Figure 4. STWAVE input and output files

Model Parameters

The model-parameter file specifies options for running STWAVE and special output points. The first line of the model parameter file, read using free format (parameters must be delimited by spaces, commas, or new lines), includes (in the following order):

IPRP = Switch for including propagation only (IPRP = 1) or both propagation and source terms (IPRP = 0). Surf-zone wave breaking is included for either option, but wind-wave generation, wave-wave interactions, and white capping are included only for IPRP = 0. In applications where the wave propagation distances are short (on the order of kilometers), propagation only is usually sufficient. For longer wave propagation distances or cases where only locally generated waves exist, the source terms should be included.

ICUR = Switch for including (ICUR = 1) or excluding (ICUR = 0) wave-current interaction. A current field must be specified (see Current Fields below) if ICUR = 1. Currents can increase (opposing current) or decrease (following current) wave height as well as change wave direction because of wave-current interaction. These interactions are strongest for shore wave periods and large current magnitudes. Smith, Militello, and Smith (1998) showed that current magnitudes less than about 1 m/sec had minor impacts on wave transformation at an East Coast inlet in Florida (peak wave periods in the range of 5-15 sec).

NSELCT = Number of special output points. The wave spectra will be saved only for these output points. Also, a file that summarizes wave height, period, and direction for these points will be written. Wave height, period, and direction are saved by the model at all grid points (see Chapter 4), but this summary file makes it easy to spot check results at critical locations or to isolate only the locations of interest.

The final information in the model-parameter file is specification of the special output points. These points are I, J (*x* grid cell index, *y* grid cell index) pairings of these special output points. There must be NSELCT pairs of numbers. The values are again read in free format and may occupy as many lines as needed.

The default name of the model parameter files is `options.std`. In SMS, the file is specified with a project name and the extension `.std`. A sample model parameter file is give in Appendix A. The sample file specifies that the model run will consider only propagation with no source terms (IPRP = 1), and wave-current interaction is included (ICUR = 1). Three output points have been selected (at I, J coordinates (15,21), (15,65), and (28,49)).

Bathymetry

The bathymetry file gives the STWAVE grid size and spacing and defines the grid bathymetry. The first line of the file, read using free format, includes (in the following order):

NI = Number of cross-shore (*x*) grid cells or columns. The value of NI, together with the grid spacing (DXINC), determines the cross-shore extent of the modeling domain and the location of the offshore grid boundary. The offshore boundary is typically placed in a region where the bathymetry contours are relatively straight and parallel and where incident wave information is available from a gauge or hindcast.

NJ = Number of alongshore (*y*) grid cells or rows. The value of NJ, together with the grid spacing, determines the alongshore extent of the modeling domain and the location of the lateral grid boundaries. The lateral extent of the grid is a balance between keeping the lateral boundaries as far away as possible from the region of engineering interest and keeping the grid domain small for computational efficiency. The grid should extend sufficiently far alongshore to include the bathymetric features that influence the engineering project (e.g., if a project is centered on a coastal inlet entrance, the entire ebb shoal and any offshore fea-tures that influence refraction should be included in the model domain).

DXINC = Grid spacing in meters, which is the same in the *x* and *y* directions. The grid spacing determines how finely bathymetric features and current fields are resolved in the model and the spatial resolution of the output fields of wave height, period, and direction. Grid spacing should be sufficient to define bathy-metric features and gradients (shoals, canyons, and channels) that are important to the engineering project. Typical resolutions are tens to hundreds of meters. For a fixed grid domain, increasing the grid resolution increases computational time.

The remainder of the file gives the water depth (relative to some datum, such as mean sea level or mean lower low water) for each grid cell in an STWAVE application, in meters. Water depths are defined as positive numbers and land elevations are negative numbers. The depths are read with a free format. The file begins with the depth at cell (1, NJ) and reads in the cross-shore direction (I = 1 to NI). The read is repeated for J = NJ-1 (I = 1 to NI), and progresses to J = 1. The default name for the bathymetry file is `depth.in`. In SMS, the file is specified with a project name and the extension `.dep`. A sample bathymetry file is given in Appendix B. The sample grid is defined as 53 cells in the cross-shore direction and 112 cells in the alongshore direction. The grid spacing is 50 m.

Incident Wave Spectra

Incident two-dimensional wave spectra are specified as energy density as a function of frequency and direction. A single input spectrum is applied along the entire offshore boundary of the STWAVE grid (the spectrum is set to zero for any land points along the boundary). Thus, it is good practice to establish the offshore boundary of the bathymetry grid along a depth contour where the wave spectrum is fairly homogeneous (no large shoals or canyons offshore of the boundary). The first line of the spectra file describes the number of frequency and direction bins in the spectra (read in free format):

NF = Number of frequency bins in the spectra. The number of frequency bins determines how finely resolved are the calculated spectra. A large number of frequency bins increases the computation time, and a small number of bins reduces model resolution. Typically, 20-30 bins are used.

NA = Number of direction bins in the spectra. This value must be set to 35, which gives 5-deg resolution in direction.

The next lines of the model parameter file specify the frequencies for model spectra (used for the input spectra, internal computations, and output spectra), starting from the lowest frequency. There must be NF frequencies specified. The frequencies are again read in free format and may occupy as many lines as needed. These frequencies should span the frequency range where significant wave energy is contained in the spectrum. This can be estimated by inspecting the input spectrum or estimating the peak period expected using the wave growth curves in the Coastal Engineering Manual (in preparation). A rule of thumb is that the spectral peak should fall at about the lower one-third of the frequency range (e.g., if the peak frequency is 0.1 Hz, the range may be 0.01 to 0.3 Hz). Wave frequencies higher (or periods shorter) than the highest frequency bin or lower than the lowest frequency bin will not be resolved by the model. Typi-cally, frequency increments are on the order of 0.01 Hz, but the increment need not be constant. West Coast applications will tend to require finer resolution focused at lower frequencies (because of long wave periods), and Gulf Coast or Great Lakes applications will tend to require coarser resolution covering a broader range of frequencies (because of shorter wave periods).

Following specification of the frequency and direction bins is a header line containing a spectrum identifier, wind information, peak frequency, and water-elevation correction:

IDD = Integer event identifier, such as a date or test number. The integer is limited to nine digits.

U = Wind speed in meters/second. This wind speed is considered constant over the entire grid. Winds that are blowing offshore (-x direction) are neglected by the model, because the model only treats generation in a half plane. For wind

directions greater than 60 deg relative the *x* axis, STWAVE underpredicts wave generation (because of the half-plane model coverage). To model large ranges of wind direction, multiple STWAVE grid orientations may be required.

UDIR = wind direction relative to the STWAVE coordinate system in degrees. Wind direction is measured counterclockwise from the *x* axis (same convention used for wave direction, see Figure 3).

FM = Peak spectral frequency in Hz. If a spectrum is specified with no energy (i.e., waves will be locally generated in the modeling domain), FM should be set to the highest frequency specified in the model parameter file.

DADD = Water-elevation correction (tide or storm surge) in meters, relative to the bathymetry datum. Users should take special care to ensure a consistent datum is used to specify the bathymetry and the water-elevation correction. The water-elevation correction is constant over the entire grid.

The header line is read in free format and is followed by the energy densities in the units meters squared/hertz/radian. The spectrum is read starting with the lowest frequency and reading all the wave directions (from -85 deg to 85 deg), then reading energy densities for all directions for the next lowest frequency, etc. The total number of energy densities read equals the number frequencies times the number of directions.

Multiple wave model runs can be executed by inserting multiple spectra, with identifying header lines, in the input file (the number of frequency and direction bins and the frequencies are not repeated for each spectrum). The model will loop through the execution until it runs out of input spectral information (model parameters and bathymetry will stay constant). If wave-current interaction is specified, the number of current fields in the current input files must equal the number of input spectra. The default name for the incident spectra file is `spec.in`. In SMS, the file is specified with a project name and the extension `.eng` (for energy density). A sample incident spectrum file is given in Appendix C. The sample spectrum file has 30 frequencies and 35 directions. The spectral frequencies are from 0.031 to 0.258 Hz, incrementing by 0.0078 Hz. The run identifier is 96031202 (12 March 1996 at 0200 GMT). The wind speed and wind direction are zero because local wind generation is not specified in the run (IPRP = 1, in the model parameter file). The peak frequency of the spectrum is 0.078 Hz (period of 13 sec), and the tide/surge elevation is 0.34 m relative to mean sea level (which corresponds to the mean sea level datum used to develop the bathymetry file).

The incident wave spectrum can be specified using a measured two-dimensional spectrum, by generating a spectrum using a parametric shape, or from a spectrum calculated by a global- or regional-scale wave model. Rarely do measured spectra have the directional resolution required by the model; thus, measured spectra require interpolation to finer resolution. A parametric spectral shape together with a directional spreading function can also be applied to specify

an incident spectrum, knowing the wave height, period, and direction. SMS includes the capability to generate incident spectra using a TMA one-dimensional shallow-water spectral shape (named for the three data sets used to develop the spectrum: TEXEL storm, MARSEN, and ARSLOE) (Bouws et al. 1985) and a $\cos^{nn}\theta$ directional distribution (see Chapter 5). To generate a TMA spectrum, the following parameters must be specified: peak wave period (T_p), wave height, water depth, and a spectral peakedness parameter (γ). The peakedness parameter controls the width of the frequency spectrum (small numbers give broad peaks and large numbers give narrow peaks). The direc-tional distribution of the spectrum is specified with a mean direction and a direc-tional spreading coefficient (*nn*). The energy in the frequency spectrum is spread proportional to $\cos^{nn}(\theta-\theta_m)$, where θ is direction of the spectral compo-nent and θ_m is the mean wave direction. Guidance for selecting γ and *nn* is given in Table 1.[1] Spectra with large peak periods are generally narrow in both frequency and direction (swell). For small peak periods, spectra are typically broad in both frequency and direction (sea).

Table 1
Approximate Spectral Peakedness and Directional Spreading Parameters

T_p, Sec	γ	nn
≤10	3.3	4
11	4	8
12	4	10
13	5	12
14	5	16
15	6	18
16	6	20
17	7	22
18	7	26
19	8	28
20	8	30

Current Fields

A current field input file is required only if ICUR = 1 in the model parameters (it is ignored if ICUR = 0). The current vector is specified as *x* and *y* compo-nents of the current at each grid cell, *u* and *v*, in the units meters/second. The *x* and *y* directions correspond to the *x* and *y* axes of the grid in the local STWAVE

[1] Personal Communication, 1998, Edward F. Thompson, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

coordinates (Figure 3). The first line of the current input file is the NI, NJ, and DXINC repeated from the bathymetry file. STWAVE checks that these values are consistent with the bathymetry file, and if they are not, model execution is terminated with the error "current field does not match depth grid size." Next, the header for the current field is given, which is an event identifier. This header is not used by the model, but is helpful to ensure that the current and spectral files coincide. Similar to the bathymetry file, the current file begins with the *u/v* pair at cell (1, NJ) and reads in the cross-shore direction (I = 1 to NI). Then the read is repeated for J = NJ-1 (I = 1 to NI), and progresses to J = 1. The current components are read in free format. The default name for the current field file is `current.in`. In SMS, the file is specified with a project name and the extension `.cur`. A sample current field file is given in Appendix D. In the sample file, the first line repeats the grid parameters from the bathymetry file. The grid is defined as 53 cells in the cross-shore direction and 112 cells in the alongshore direction with a grid spacing of 50 m. The event identifier for the current field is 96031202, which matches the event identifier in the incident spectrum file. As with the spectral file, multiple wave model runs can be executed by inserting current fields (with their event-identifier headers) in the input file (as well as the same number of input spectra in the spec.in file). The model will loop through the execution until it runs out of input spectral and current information.

4 Output File Description

STWAVE has three output files. These files contain wave spectra at the selected output points; wave height, period, and direction at the selected output points; and fields of wave height, period, and direction over the entire STWAVE modeling domain. If multiple incident wave spectra are specified in the input file (and current fields, if wave-current interaction is specified), then output from each of these model runs is appended to the output files.

Selected Wave Spectra

Wave spectra at selected grid cells, specified in the model parameters file (see Chapter 3, Input File Description), are saved in a spectral output file. Similar to the input spectra file, the first line of the output file describes the number of frequencies and number of directions (NF and NA), and the following lines give the frequencies. Each spectrum in the file is proceeded by the following header information:

IDD = Integer event identifier, specified in the incident wave spectrum file.

I = Integer x grid cell index of the special output point, specified in the model parameter file.

J = Integer y grid cell index of the special output point, specified in the model parameter file.

N = Integer index of the special output point (values are 1 to NSELCT, based on the order in which the points are specified in the model parameter file).

The header format is (i10,3i5). Following the header line, the output spectrum is written in the same order and units in which the incident spectrum was read. Energy densities are given in the units meters squared/hertz/radian. The spectrum is written starting with the lowest frequency and writing energy density for all wave directions (from -85 deg to 85 deg), followed by the energy densities for all directions for the next lowest frequency, etc. The format of the energy densities is (17f6.3).

The spectra will be written to the file in an order based on the I cell index, starting from the smallest index and proceeding to the largest index. This is because spectra are not saved over the entire grid, so the output spectra are written to the file as the grid column is solved and then are overwritten in memory. Thus, the order may not coincide with N = 1, NSELCT. The default file name for the output spectra file is `spec.out`. In SMS, the file is specified with a project name and the extension `.obs`.

Selected Wave Parameters

The wave parameters H_{mo}, T_p, and mean wave direction, θ_m, at selected grid cells, specified in the model parameters file (see Chapter 3, Input File Description), are saved in a selected parameter output file. The selected grid cells are the same locations where spectra were saved. For each output point, the following information is written:

IDD = Integer event identifier, specified in the incident wave spectrum file.

I = Integer *x* grid cell index of the special output point, specified in the model parameter file.

J = Integer *y* grid cell index of the special output point, specified in the model parameter file.

H_{mo} = Zero-moment wave height at cell (I, J), in meters.

T_p = Peak wave period at cell (I, J), in seconds.

θ_m = Mean wave direction at cell (I, J), in degrees relative to the STWAVE grid (see Figure 3).

The format of each line is (i10,2i3,f6.2,f6.1,f6.0). Information for each selected grid cell is written on a separate line in the file. The default file name is `selhts.out`. This file is not used in SMS because wave height, period, and direction for all grid cells are displayed graphically on the screen over the entire domain (values at any cell in the domain are displayed by clinking on the cell with the mouse). Examples of two selected wave parameter files are given in Chapter 6.

Wave Parameter Fields

The wave parameters H_{mo}, T_p, and 2_{m} are also saved for all grid cells into a wave field file. Written first in the file are the grid dimensions (NI and NJ) and grid spacing (DXINC) repeated from the bathymetry input file. Next in the file is the event identifier (IDD from the incident wave spectrum file) in the format (i10).

After this header line, all the wave heights are written, beginning at cell (1, NJ) and proceeding in the cross-shore direction (I = 1, NI). The write is repeated for each grid row from J = NJ-1 to J = 1. The format is (16f5.2). Following the wave heights, the wave periods are written in the same order with the format (16f5.1). Then the wave directions are written (again in the same order) with the format (16i5). If multiple input spectra are specified, the event identifier and the wave heights, periods, and directions for each condition are appended to the end of the file.

The default file name for the wave field file is wavfld. In SMS, the file is specified with a project name and the extension .wav.

5 SMS User Interface

Information contained in the STWAVE input files (Chapter 3) and output files (Chapter 4) is conceptually easy to understand, but practically, these files contain large amounts of data that can be difficult to generate and interpret. To assist STWAVE users in generating input files and visualizing output files, a user interface has been built for STWAVE within the Surface-water Modeling System (Brigham Young University Engineering Computer Graphics Laboratory (ECGL) 1997). The SMS interface supports grid generation, interpolation of current fields, generation of input spectra, visualization of wave heights, periods, and directions, and visualization of output spectra. STWAVE will be released SMS version 6.1 in early 1999. Corps of Engineers SMS users are supported through the Coastal and Hydraulics Laboratory (*http://hlnet.wes.army.mil/software/sms/*), and non-Corps users can get information from ECGL (*http://www.ecgl.byu.edu*). SMS is not required to run STWAVE, but it is a powerful tool to efficiently develop and visualize input and output files.

This chapter provides a brief tutorial on the application of STWAVE within SMS. It does not cover all the SMS features, but describes a typical application of the model. For coastal inlets, it is common to run the finite-element circulation model ADCIRC (Luettich, Westerink, and Scheffner 1992) to calculate water-surface elevations and current fields, as well as to run STWAVE. The example application starts with an ADCIRC finite-element bathymetry grid (file ponce.grd) and a current field generated by ADCIRC (file ponce.64). These gridded data are converted to "scatter" data (random data points that are not associated with a grid, but with x and y locations). From these scatter data, a Cartesian bathymetry grid and current field are generated. Next, other required model input (input spectrum and model parameters) is entered and the model is executed. Finally, postprocessing of the data is described, including visualiza-tion of the bathymetry and wave heights, directions, heights, and spectra.

Converting ADCIRC to Scatter

Reading in the ADCIRC files

1. Go to the *Mesh Module* and choose *Data|Switch Current Model…* Click on *ADCIRC* and push OK.

2. Go to *ADCIRC|Open Simulation…* Toggle the *Control* (*.15) button off and make sure the *Open Grid File* button is on. Click the button under *Open Grid File* and choose `ponce.grd`. Push OK to read in the mesh file.

3. Go to *Data|Data Browser* and click the *Import…* button at the bottom left. Change the *File Type* to ADCIRC and push OK. Select `ponce.64` and push OK.

4. After the data is read in, push the *Convert* button (still in the *Data Browser*) in the *Vector Data Set* section. Choose *Vx and Vy* to split the vector data into its components. Rename the *Vx and Vy* data sets to "Current_x" and "Current_y" and push *Convert*. When text appears telling you that the conversion is finished, push *Done*.

5. Push *Done* again to exit the *Data Set Browser*.

Converting to scatter

1. Go to *Data|Mesh -> Scatterpoint*, leave the name as "Scatter," and push OK.

2. Switch to the *Scatter Module* and zoom in on the dense part as shown in Figure 5. Choose *Edit|Select With Poly* and click on the screen to select enough scatter points to surround the area where the grid will be created. Double click on the screen to close the polygon and select the points.

3. Go to *Interpolation|Create Subset*. Rename the scatter set to "Grid" and push OK.

4. Push the *Frame* button to show both scatter sets.

5. Select the *Select Scatter Sets* tool and click in the box on the screen belonging to the larger scatter set called "Scatter" and push the DELETE button. This deletes the unnecessary data.

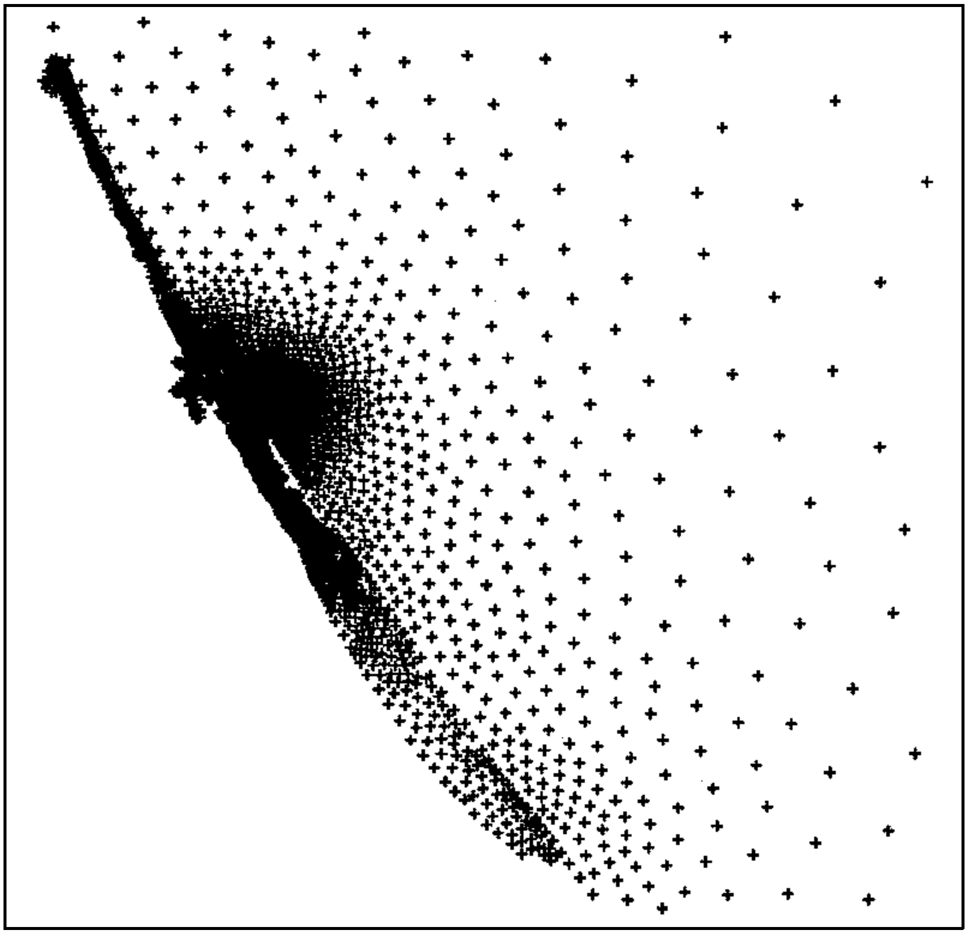

Figure 5. Zoomed-in view of scatter data set

Creating the Cartesian Grid

Creating the Cartesian grid frame

1. Switch to the *Map Module*. Go to *Feature Objects|Coverages…* and switch the *Coverage Type* to *Cartesian Grid*. Push OK.

2. Go to *Feature Objects|Grid Frame* and push the *New Grid* button.

3. Drag and resize the grid frame by dragging the corners or edges until the grid frame fits over the desired area. Dragging a corner resizes the frame. Dragging an edge moves the entire frame.

4. Rotate the grid by dragging the circle at the bottom right corner of the frame. Rotate the frame until the circle is at the left of the screen. The origin of the grid frame is the frame corner at the top of the screen. Note: It may be necessary to make the grid frame smaller and then push OK to

exit the dialog. You can zoom in on the desired area and then position the grid frame by reopening the grid frame dialog with *Feature Objects|Grid Frame*.

5. Push OK when you are done positioning the frame to appear as Figure 6.

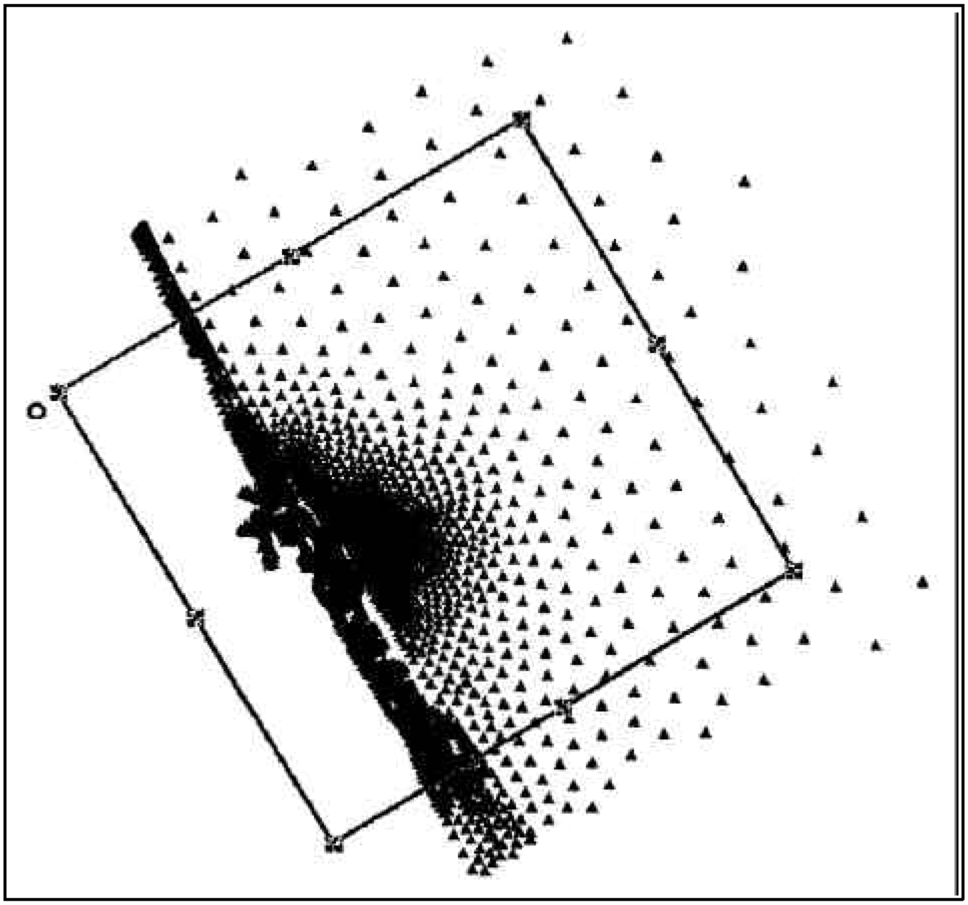

Figure 6. Grid frame positioned over scatter data set

Creating the land and ocean polygons

1. Go back to the *Mesh Module* and choose *Data|Material->Feature* and use the active coverage. This creates map module polygons around the boundaries of the mesh.

2. Go to *Display|Display Options…* and click *All off* and OK to turn off the elements and nodes.

3. Switch back to the *Map Module*.

4. Select the *Create Arcs* tool and create arcs surrounding the left part of the grid frame (outside of the polygons created in Step 1). Connect the arcs with vertices of the ocean polygon as shown in Figure 7.

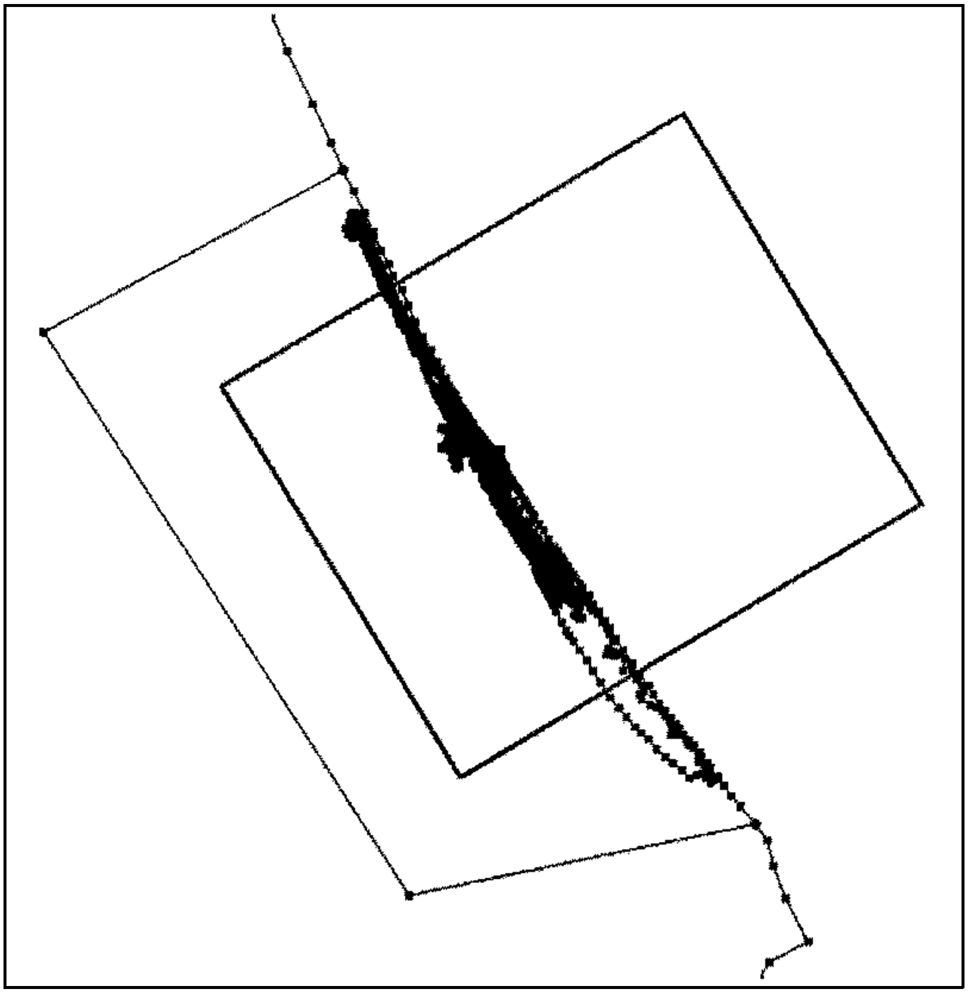

Figure 7. Arc created around border of grid frame

5. Go to *Feature Objects|Build Polygons* and push OK at the prompt.

6. Double click in the new polygon that you created (on the left side) and select *Land* and push OK. The default for the polygons created earlier is *Ocean*.

Mapping to the grid

1. Go to *Feature Objects|Map->2D Grid*.

2. Set the *Cell Options* to *Number of Columns* and set the value to 50.

3. Toggle *Create Functions* on.

4. Click the button that is to the right of *Depth*. This opens the *Scatter Options* dialog.

5. Select the function ("elevation") that will be used to interpolate the depth and push OK.

6. Click the button that is to the right of *Current x*. Select the function "Current_x". This will be used to interpolate the X component of current.

7. Change *Time Steps* to *Multiple* and change *Time Step Interpolation* to *Interpolate.*

8. Enter the 261000 in *Beg time*, 900 in *Step size* and 3 in *Number steps*. This tells *SMS* to create current data at time 261000, 261900, 262800, and 263700 sec (four sets of values around three steps of 15 min each).

9. Select OK to exit the *Scatter Options* dialog.

10. Click the button that is to the right of *Current y*. Select the function "Current_y". This will be used to interpolate the Y component of current. You do not need to repeat the time step definition, since both components share the same parameters.

11. Select OK to exit the *Scatter Options* dialog.

12. Push OK to create the Cartesian grid.

13. Switch to the *Cartesian Grid* module to edit and look at the completed grid.

Note on interpolation (When interpolating you can specify a single time step or multiple steps. Single times can come from any time in the data set or interpolated between two of these times. For multiple steps, you can specify to match the steps from the data set for a specified number of steps, or you can specify a new time step size and the number of steps. SMS will generate one set of values at the beginning time specified, and one at the end of each time step. Therefore, there will be "n+1" sets of currents if you specify "n" time steps.)

Editing the Grid and Running STWAVE

Generating spectral energy distribution

1. In the *Cartesian Grid* module, choose *STWAVE|Spectral Energy*.

2. Push the *Generate Spectrum* button. Enter 40 for *Num. Frequencies*, 0.01 for the *Frequency Step*, and 0.03 for the *Starting Frequency*.

3. Push the *Generate* button and then OK to exit the *Spectral Energy* dialog.

Model control

1. Select *STWAVE|Model Control*.

2. Change the *Wind* to *Propagation Only* and push OK to exit the dialog.

Selecting monitoring stations

1. Select the *Select Cell* tool.

2. Select the cell with the IJ location of I = 34 and J = 30. The location can be seen in the bottom right in the *Edit Window* when a cell is selected. (Click on the screen to select a cell.)

3. While the cell is still selected, choose *STWAVE|Assign Cell Atts*. Turn the *Monitoring Station* toggle on and push OK.

4. Repeat Steps 2 and 3 and change the cells at I = 17, J = 18 and I = 25, J = 35 to be *Monitoring* cells.

Saving the simulation

To save the simulation, select *STWAVE|Save Simulation* and enter `ponce.sim`.

Running STWAVE

1. To run *STWAVE*, select *STWAVE|Run STWAVE*.

2. Click the *folder* button and *path to* and select the *STWAVE* executable. Push OK.

3. A window will appear and stay up while *STWAVE* runs. When *STWAVE* is finished, the window will disappear.

Postprocessing

Visualizing the STWAVE solution

1. Open the solution files by selecting *STWAVE|Open Simulation*.

2. Select `ponce.sim` and push OK.

3. Select *Display|Display Options*. Turn the *Contours* and *Vectors* toggles on.

4. Push the *Contour Options* button and select *Color Fill Between Contours* as the *Contour Method*. Push OK.

5. Push the *Vector Options* button and change the *Shaft Length* to *Define min and max*.

6. Set the *Min length* to 25 and the *Max length* to 50. Push OK.

7. Push OK to exit the *Display Options* dialog.

Visualizing bathymetry

1. Go to *Data|Data Browser* and select the scalar function named “depth.” Push *Done* to exit the dialog.

2. The contours show the water depth in the ocean.

Visualizing the direction field

1. Go to *Data|Data Browser* and select the vector function named “wave.” Push *Done* to exit the dialog.

2. The vector arrows show the wave direction field.

Visualizing the wave height

1. Go to *Data|Data Browser* and select the scalar function named “Height.” Push *Done* to exit the dialog.

2. The contours show the wave height.

Visualizing the observation (monitoring cells) spectra

1. Go to *STWAVE|Spectral Energy*.

2. Push the Contour Options button, select *Color Fill Between Contours*, and push OK.

3. Push the *Data Browser* button and select the scalar data set named “Node_34_30.” Push *Done*.

4. The contours show the observation spectra for the node at I = 34, J = 30.

5. Push OK to exit the *Spectral Energy* dialog.

6 Example Applications

In this chapter, two example applications of STWAVE are given. The purpose of these examples is to demonstrate how the model can be applied and provide sample problems that a new user can follow to learn the mechanics of model application. The first example is wave transformation and wave-current interaction at a complex coastal inlet. The second example is wind-wave generation over a simple bathymetry. The first example focuses on wave propagation and the second example on wave generation (using the source term options).

Example 1: Wave Propagation at Ponce de Leon Inlet

The first example is based on a field site, Ponce de Leon Inlet, located on the east coast of Florida. The nearshore bathymetry at Ponce Inlet is complex because of the presence of the inlet, a navigation channel, jetties, and a large ebb shoal. Tidal currents at the inlet can exceed 1 m/sec. Engineering problems at Ponce Inlet that require information about the nearshore wave field include scour in the inlet throat near the north jetty, erosion of the north spit in the interior of the inlet, migration of the navigation channel, and possible breaching shoreward of the north jetty. More information about Ponce Inlet is given in a reconnaissance report by the U.S. Army Corps of Engineers (1993). Also, a field-data collection program conducted at Ponce Inlet from September 1995 through September 1997 is documented by King et al. (1999). STWAVE applications to Ponce Inlet are documented in Smith, Militello, and Smith (1998) and Smith and Smith (in preparation).

Model input

Model parameters. Figure 8 shows the bathymetry contours within the STWAVE modeling domain selected for Ponce Inlet. The offshore boundary location is selected at an approximate depth of 18 m. This depth is chosen because the bottom contours are fairly straight and parallel at this depth (out of the influence of the ebb shoal) and because a wave gauge (designated as DWG1

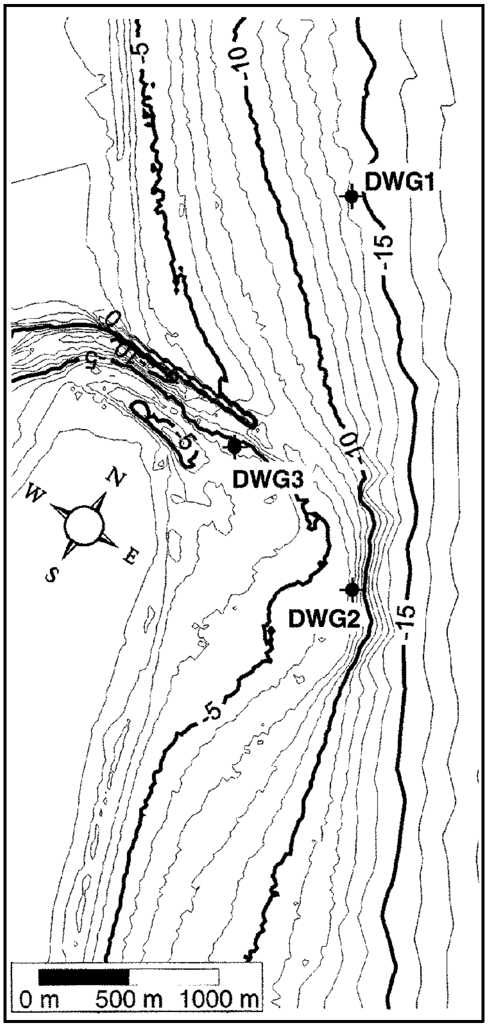

Figure 8. Ponce Inlet bathymetry and gauge positions

in Figure 8) was located near this contour to provide the input wave conditions. The lateral boundaries of the domain are positioned away from the influence of the inlet, to areas of fairly straight and parallel depth contours. A 50-m grid cell spacing is selected to resolve the ebb shoal and inlet bathymetry. To cover the domain with 50-m resolution requires 53 cells across the shore (NI) and 112 cells alongshore (NJ). Typical wave periods for this site are 15 to 5 sec (0.0667 to 0.2 Hz). To resolve this range, 30 frequency bins are used with an initial frequency of 0.031 Hz and a frequency increment of 0.0078 Hz (range of frequencies is 0.031 to 0.258 Hz). Because the wave propagation distances on the Ponce Inlet grid are short (2 km), source terms are neglected (IPRP = 1). Even with strong winds, wave growth over the short distance would be small. Wave-current interaction, though, could be significant near the inlet, so ICUR = 1 to include wave-current interaction. Selected model output locations are chosen to match three directional wave gauge positions at Ponce Inlet (see Figure 8). The depths at the three gauges are approximately 14, 7, and 5 m. The gauges are located near the offshore boundary, on the ebb shoal, and in the outer inlet throat (north of the ebb shoal). The parameter input file for this case is given in Appendix A.

Bathymetry. The bathymetry contours for Ponce Inlet are shown in Figure 8. The grid was developed using a grid generator (see Chapter 5), which accepts random *x, y,* and depth triplets and interpolates them onto a Cartesian grid with a given origin, orientation, and resolution. In this case, high-resolution bathymetry near the inlet was obtained from a Scanning Hydrographic Operational Airborne Lidar System (SHOALS) (Lillycrop, Parson, and Irish 1996) survey and supplemented with National Oceanic and Atmospheric Administration digital bathymetry (used to define offshore and bay bathymetry) and shorelines. The north jetty at Ponce Inlet is represented in the model as a series of land cells. The jetty is specified as being three grid cells wide, which is wider than the real structure. Three cells are required to block wave energy from propagating through the structure. Future upgrades to the model will provide the capability to

represent structure widths that are less than the grid cell spacing. The bathymetric input file for Ponce Inlet is given in Appendix B.

Incident wave spectrum. The incident wave spectrum for Ponce Inlet was generated using a TMA spectral shape (with a spectral peakedness parameter, γ = 5.0), $\cos^{nn}\theta$ directional distribution (with nn = 12), H_{mo} = 5.2 m, T_p = 12.8 sec, and θ_m = -7 deg (see Table 1 for guidance on spectra shape and directional spreading parameters). The input spectrum file is given in Appendix C. These incident conditions represent extreme high wave conditions measured at Ponce Inlet in March 1996.

Current field. The current field for Ponce Inlet was generated using the tidal circulation model ADCIRC (Luettich, Westerink, and Scheffner 1992). The current field output from ADCIRC was interpolated onto the STWAVE grid using SMS (see Chapter 5). The input current field is given in Appendix D. The current field is plotted in Figure 9.

Results

The wave parameters for the three gauge positions at Ponce Inlet are given in the selhts.out file:

Date	I	J	H_{mo}	T_p	θ_m
96031202	15	21	5.25	12.8	-6.
96031202	15	65	4.13	12.8	-5.
96031202	28	49	2.86	12.8	18.

At the first gauge position (I = 15, J = 21), the wave height has shoaled slightly (from 5.2 m at the boundary to 5.25 m) and turned slightly more shore normal (from -7 deg at the boundary to -6 deg). At the second gauge (I = 15, J = 65), located on the ebb shoal, the wave energy has dissipated because of breaking (reduction of 21 percent in wave height from the offshore boundary). At the most shoreward gauge (I = 28, J = 49), the energy has been dissipated significantly (45-percent reduction in wave height from the offshore boundary) and the mean direction has refracted from -7 deg at the boundary to 18 deg in the outer throat. The wave directions at this gauge are turning to align normal to the ebb shoal that is located to the south of the gauge (positive angles are more southerly and negative angles are more northerly).

The trends of wave-height reduction and turning of the wave angle can also be illustrated by examining the one-dimensional wave spectra plotted in Figure 10. The shape of the spectra stays quite similar, but the energy is reduced because of depth-limited breaking from the offshore to the outer throat gauge. Another way to view the spectrum is to integrate over all frequencies to examine the directional distribution of the wave energy (Figure 11). The directional distribution narrows as well as reduces in energy between the offshore and ebb shoal gauges because of

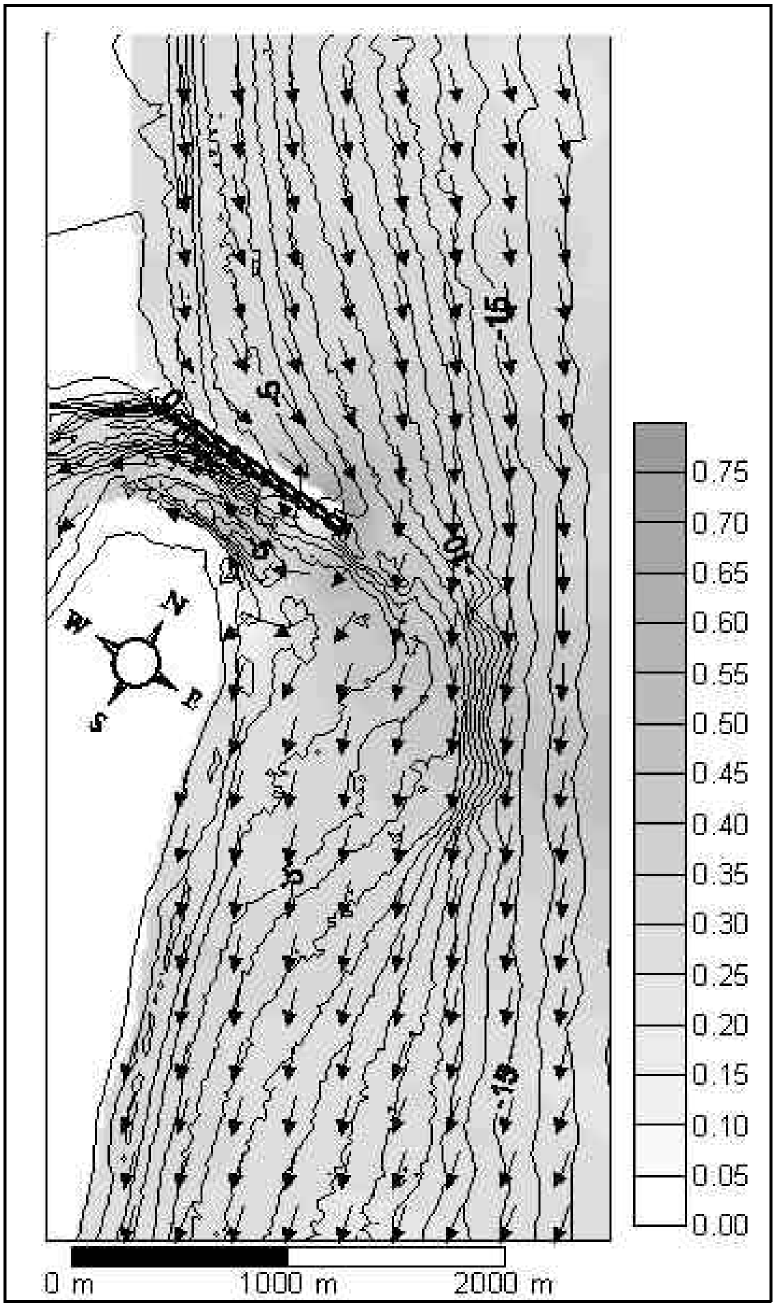

Figure 9. Currents for Ponce Inlet example

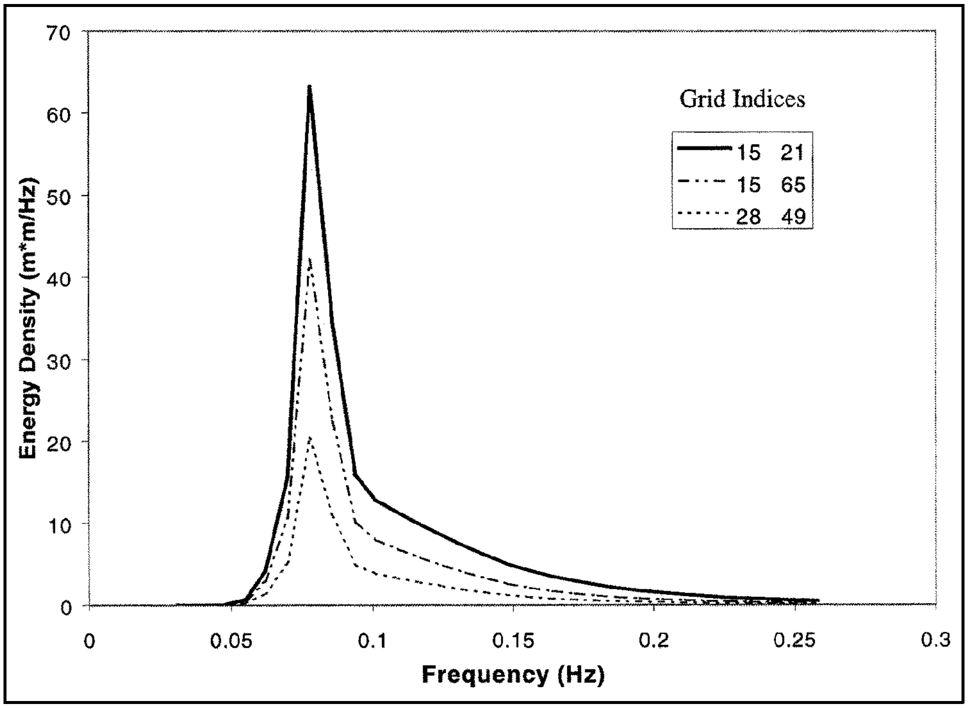

Figure 10. One-dimensional wave spectra for Ponce Inlet

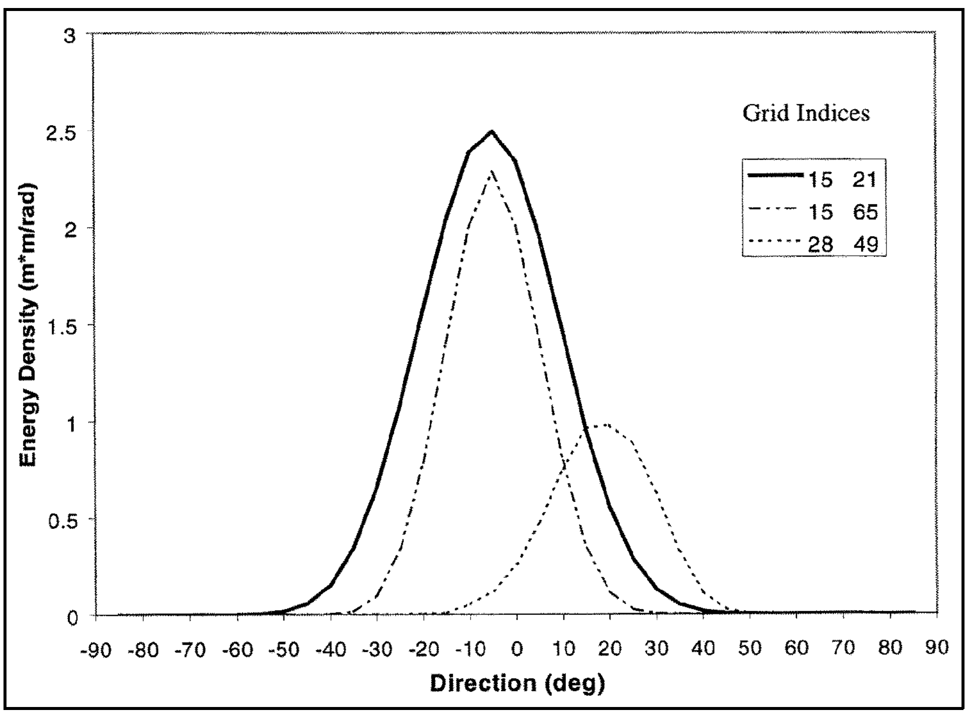

Figure 11. Directional distribution of Ponce Inlet wave spectra

refraction. Between the offshore/ebb shoal gauges and the the outer throat gauge, the mean direction shifts by 25 deg, again because of refraction.

Figure 12 shows a contour plot of the wave heights over the entire STWAVE domain. The gray shade contours represent wave height, and the background line contours represent the bathymetry. For these incident wave conditions, the wave-height variations closely follow the depth contours, because depth-limited breaking in the dominant process and thus the wave height contours mimic the depth contours. For cases with less extreme incident wave heights, the maximum wave heights are found on the ebb shoal, where energy is focused by refraction.

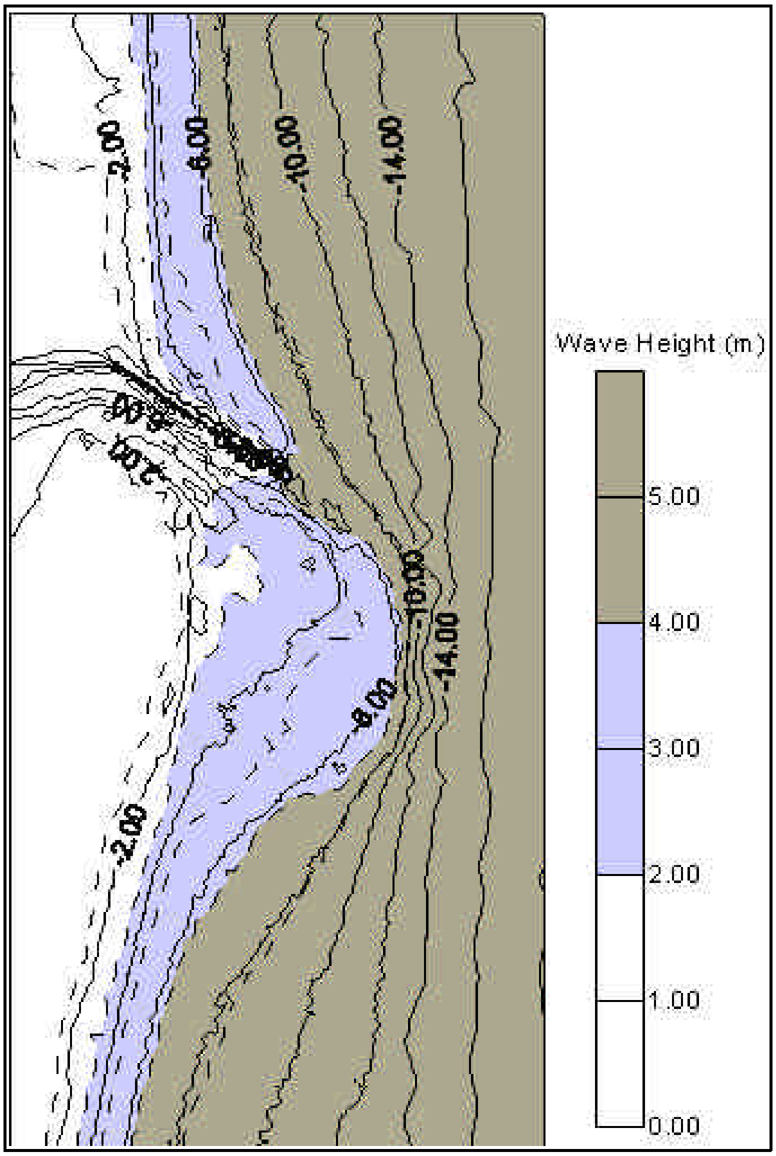

Figure 12.   Wave-height contours for Ponce Inlet example

Example 2: Wind-Wave Generation

For the second example, consider a bay that is rectangular in shape, 20 km east-west and 10 km north-south. For practical purposes, the bay is isolated from ocean waves. The water depth is a constant 15 m, with a gentle side slope of 1:100 at the eastern end of the lake and vertical walls on the other three sides. The bay has a rectangle shape with simplified bathymetry, so users can easily develop the input bathymetry. The grid domain is shown in Figure 13. The area of interest is the eastern shoreline of the bay, where a project is planned to mine sand to construct a beach. For a project such as this, wave information may be required to evaluate sediment-transport rates at the borrow site to estimate infilling rates or evaluate longshore and cross-shore sediment-transport rates at the newly constructed beach to estimate the project's life and renourishment requirements.

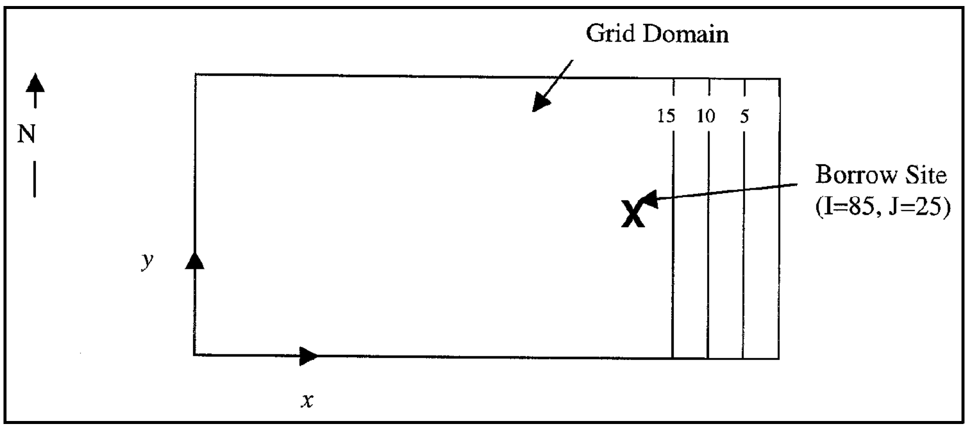

Figure 13. Schematic of Example 2 grid domain

Model input

Model parameters. Both wave propagation and source terms (IPRP = 0) are required for this example, but currents are negligible (ICUR = 0). The special output points are selected to examine wave growth along the major axis of the lake. The borrow site is located near grid cell (85,25). The model parameter input file is:

```
0  0  10
  5  25
 25  25
 50  25
 75  25
 85  25
 95  25
 97  25
 98  25
```

```
 99  25
100 25
```

Bathymetry. The bathymetry and shoreline are very simple, and fine bathymetric resolution is not required. A grid spacing (DXINC) of 200 m is selected, with 101 cells in the cross-shore (NI) and 51 cells in the alongshore (NJ). To simplify the input file for this example, the bay is assumed to have vertical walls on its the north, south, and west shores and a 1:100 slope on the eastern shore. The depth in all grid cells along the entire grid boundary is set to -1 for land. The first two grid rows (J = 51 and J = 50) of the depth file are given below:

```
100 51  200.
 B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.
 B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.
 B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.
 B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.
 B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.
 B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.  B1.
 B1.  B1.  B1.  B1.  B1.
  B1. 15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.
 15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.
 15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.
 15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.
 15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.
 15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  13.  11.   9.
  7.   5.   3.   1.  B1.
```

The full depth file would repeat the second series above for rows J = 49 through 2, and the depths for row J = 1 would again all be -1., identical to the first series in the file. Note that the first line in the depth file represents the north edge of the grid (J = NJ), reading from west to east (I = 1,NI), and the last series in the files would be the southern edge of the grid (J = 1).

Incident wave spectrum. Twenty frequency bins are used with an initial frequency of 0.04 Hz and a frequency increment of 0.04 Hz. This coarse frequency resolution is sufficient because, even at high wind speeds, the 20-km fetch will limit peak wave periods to approximately 5 to 6 sec. The input spectrum is very simple for this example case. Because the bay is treated as an enclosed basin, the spectrum on the “offshore” boundary (the western land boundary for this case) is zero. The input spectrum includes the header with the date and wind information, followed by 700 zeros (20 frequencies by 35 directions). For a date identifier of 980923, a wind speed of 20 m/sec, a wind direction of 0 deg relative to the STWAVE grid (wind blowing from the west, for this example), a peak frequency of 0.8 Hz (set to the highest frequency because there is no energy in the input spectrum), and 0.0 m water-elevation correction; the beginning of the spectrum file is given by:

20 35
0.04 0.08 0.12 0.16 0.20 0.24 0.28 0.32 0.36 0.40
0.44 0.48 0.52 0.56 0.60 0.64 0.68 0.72 0.76 0.80
980923 20. 0. 0.8 0.

In the input file, these lines would be followed by 700 zeros (35 directions by 20 frequencies) to represent an incident spectrum with no energy.

Current field. No current field file is specified for this case.

Results

The results of greatest interest for this case are the wave parameters at the proposed borrow site (I = 85, J = 25). The wave height is 1.52 m, the peak period is 4.6 sec, and the direction is 0 deg (from the west, for this grid orientation). The output file with selected wave parameters is given below (header has been added).

Date	I	J	H_{mo}	T_p	θ_m
980923	25	25	0.86	3.2	0.
980923	50	25	1.22	3.9	0.
980923	75	25	1.45	4.4	0.
980923	85	25	1.52	4.6	0.
980923	95	25	1.55	4.7	0.
980923	96	25	1.53	4.7	0.
980923	97	25	1.50	4.7	0.
980923	98	25	1.47	4.8	0.
980923	99	25	1.23	4.8	0.
980923	100	25	0.59	4.8	0.

These output wave parameters across the long axis of the bay demonstrate the wave growth as a function of distance along the fetch. These wave heights and periods are plotted as a function of distance in Figure 14. The wave height grows with fetch until the depth decreases on the eastern shore of the lake, and the wave height decays because of depth-limited breaking. The wave direction down the long axis of the lake is aligned with the wind direction (0 deg). Figure 15 shows selected one-dimensional spectra along the long axes of the lake (legend provides I, J locations). Moving from west to east (I = 25 to 95), the peak frequencies decrease (peak periods increase) and the total energy increases, as the waves grow from input wind energy. Between I = 95 and 100, the energy density decreases because of depth-limited breaking. These one-dimensional spectra were calculated from the `spec.out` file by integrating the spectra over all directions.

To evaluate the impacts of the borrow site on the shoreline or the sediment infilling rate at the borrow site, additional STWAVE runs would be required. Typically, the local wave climate would be examined, and representative as well as maximum wind conditions would be used as input for multiple model runs.

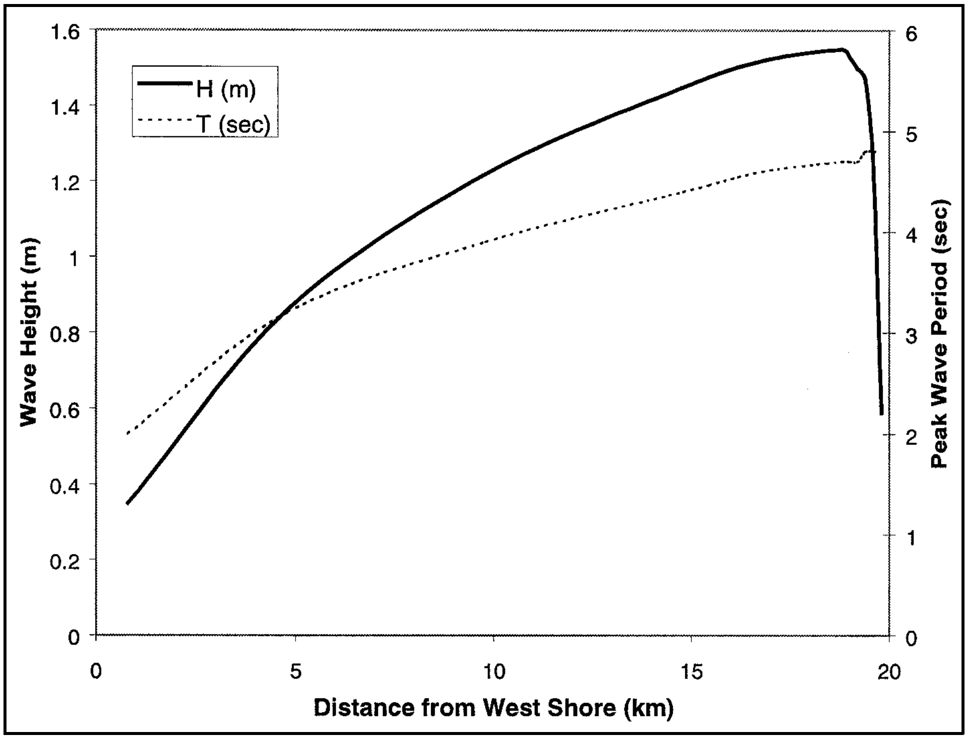

Figure 14. Wave height and period as a function of distance for 20 m/sec wind speed

Results from these runs would then be used statistically to evaluate sediment-transport potential at the borrow site and along the shoreline. Note that the strongest wind speed does not necessarily lead to the largest waves or largest sediment-transport rates. Wind direction is also a critical parameter.

This example of wave growth was for a completely enclosed basin. The wave growth capabilities of the model are also applicable on the open coast. For open-coast applications, the input spectrum would likely not equal zero, and the offshore and lateral grid boundaries would not be land. For open coastal applications, the local wave generation (represented by the source terms) is often an essential process, increasing the wave height near shore and altering wave directions.

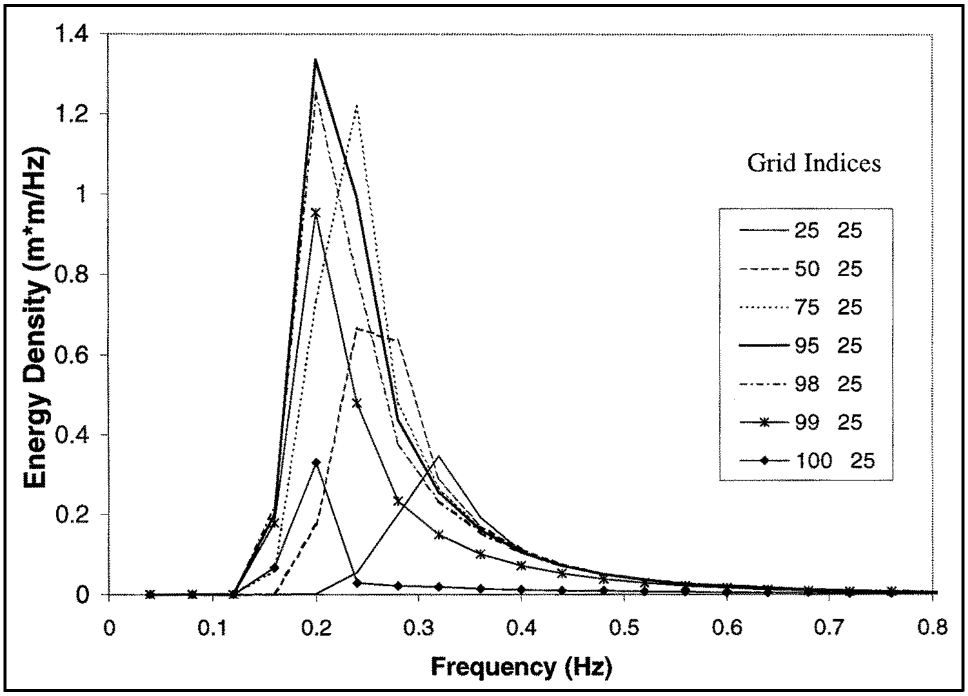

Figure 15. One-dimensional wave spectra for 20 m/sec wind speed

References

Battjes, J. A. (1982). "A case study of wave height variations due to currents in a tidal entrance," *Coast. Engrg.* 6, 47-57.

Battjes, J. A., and Janssen, J. P. F. M. (1978). "Energy loss and set-up due to breaking of random waves." *Proc. 16th Coast. Engrg. Conf.*, ASCE, 569-587.

Brigham Young University Engineering Computer Graphics Laboratory. (1997). "Surface-water modeling system reference manual." Brigham Young University, Provo, UT. (*http://hlnet.wes.army.mil/software/sms/docs.htp*)

Bouws, E., Gunther, H., Rosenthal, W., and Vincent, C. L. (1985). "Similarity of the wind wave spectrum in finite depth waves; 1. Spectral form," *J. Geophys. Res.* 90(C1), 975-986.

Coastal Engineering Manual. U.S. Army Engineer Waterways Experiment Station, Coastal and Hydraulics Laboratory, Vicksburg, MS, in preparation.

Davis, J. E. (1992). "STWAVE theory and program documentation." Coastal Modeling System User's Manual. Chapter 8, Instruction Report CERC-91-1, Supplement 1, M. A. Cialone, ed., U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Hasselmann, K., Barnett, T. P., Bouws, E., Carlson, H., Cartwright, D. E., Enke, K., Ewing, J. A., Gienapp, H., Hasselmann, D. E., Kruseman, P., Meerburg, A., Muller, P., Olbers, D. J., Richter, K., Sell, W., and Walden, H. (1973). "Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP)," *Deut. Hydrogr. Z.*, Suppl. A, 8(12), 1-95.

Jonsson, I. G. (1990). "Wave-current interactions." *The sea*. Chapter 3, Vol. 9, Part A, B. LeMehaute and D. M. Hanes, ed., John Wiley & Sons, Inc., New York.

King, D. B., Smith, J. M., Militello, A., Waller, T., and Stauble, D. K. (1999). "Ponce de Leon Inlet, Florida site investigation, Report 1: Selected portions of long-term measurements 1995-1997," Technical Report CHL-99-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Lillycrop, W. J., Parson, L. E., and Irish, J. L. (1996). "Development and operation on the SHOALS airborne lidar hydrographic survey system." *Laser remote sensing of natural waters: From theory to practice*. V. I. Feigels and Y. I. Kopilevich, ed., Proceedings, International Society for Optical Engineering (SPIE) 2964, 26-37.

Luettich, R. A., Westerink, J. J., and Scheffner, N. W. (1992). "ADCIRC: An advanced three-dimensional circulation model for shelves, coasts, and estuaries, Report 1: Theory and methodology of ADCIRC-2DDI and ADCIRC-3DL," Technical Report DRP-92-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Mei, C. C. (1989). *The applied dynamics of ocean surface waves*. World Scientific Publishing, Singapore.

Miche, M. (1951). "Le pouvoir reflechissant des ouvrages maritimes exposes a l' action de la houle." *Annals des Ponts et Chaussess*, 121e Annee, 285-319 (translated by Lincoln and Chevron, University of California, Berkeley, Wave Research Laboratory, Series 3, Issue 363, June 1954).

Resio, D. T. (1987). "Shallow-water waves. I: Theory," *J. Wtrway., Port, Coast., and Oc. Engrg.*, ASCE, 113(3), 264-281.

__________. (1988a). "Shallow-water waves. II: Data comparisons," *J. Wtrway., Port, Coast., and Oc. Engrg.*, ASCE, 114(1), 50-65.

__________. (1988b). "A steady-state wave model for coastal applications." *Proc. 21st Coast. Engrg. Conf.*, ASCE, 929-940.

Resio, D. T., and Perrie, W. (1989). "Implications of an f^{-4} equilibrium range for wind-generated waves." *J. Phys. Oceanography* 19, 193-204.

Smith, J. M., Militello, A., and Smith, S. J. (1998). "Modeling waves at Ponce de Leon Inlet, Florida." *Proc. 5th International Workshop on Wave Hindcasting and Forecasting*. Environment Canada, Downsview, Ontario, 201-214.

Smith, J. M., Resio, D. T., and Vincent, C. L. (1997). "Current-induced breaking at an idealized inlet." *Proc. Coastal Dynamics '97*, ASCE, 993-1002.

Smith, S. J., and Smith, J. M. "Modeling waves at Ponce de Leon Inlet, Florida," Submitted to *J. Wtrway., Port, Coast., and Oc. Engrg.*, ASCE.

U.S. Army Corps of Engineers, Jacksonville District. (1993). “Navigation study for Ponce de Leon Inlet, Volusia County, Florida -- 14310.” Reconnaissance Report, U.S. Army Engineer District, Jacksonville, Jacksonville, FL.

Appendix A
Sample Model Parameter File

The parameters required to run STWAVE are specified in the `options.std file`. A description of the file and formatting is given in Chapter 3 of the main text. An example parameter file for Ponce de Leon Inlet, Florida (see Example 1 in Chapter 6 – main text) is given below:

```
1   1   3
15 21
15 65
28 49
```

Appendix B
Sample Bathymetry File

The bathymetry required to run STWAVE is specified in the `depth.in` file. A description of the file and formatting is given in Chapter 3 of the main text. An example of the first seven rows (starting with J = NJ) of the bathymetry file for Ponce de Leon Inlet, Florida (see Example 1 in Chapter 6 – main text) is given below (depths in meters relative to mean sea level):

```
53 112  50.0
 17.9093 17.6657 17.4214 17.1925 16.9141 16.6358 16.3377 16.0289 15.7200 15.4130
 15.0553 14.6698 14.3101 13.9923 13.7952 13.5981 13.3654 13.0974 12.7856 12.4416
 12.0976 11.6441 11.1662 10.5809 10.9137 10.5209 10.4223 10.2180 10.0181  9.5797
  9.3289  9.1748  9.0352  8.7189  8.5227  8.1932  7.9538  7.7774  7.3291  6.9325
  6.4268  5.9270  5.3055  4.6770  4.1037  3.3492  2.7907  2.2752  1.6784  1.0786
  0.6400  0.6400  0.6400
 17.8912 17.6474 17.4032 17.1589 16.9146 16.6455 16.3367 16.0278 15.7146 15.3931
 15.1025 14.7452 14.3855 14.0510 13.8539 13.6568 13.3814 13.0899 12.7426 12.3953
 12.0504 11.3595 11.2053 11.0999 10.7788 10.4919 10.4072 10.1708  9.7571  9.4712
  9.2965  9.1355  8.7766  8.5754  8.3478  8.2013  7.9531  7.5586  7.2776  6.7930
  6.4597  5.6139  5.1999  4.6779  3.9818  3.2214  2.6701  2.1188  1.5675  1.0081
  0.6400  0.6400  0.6400
 17.8730 17.6292 17.3849 17.1414 16.9177 16.6265 16.2662 15.9447 15.6231 15.3016
 15.0376 14.7832 14.4608 14.1097 13.9126 13.6184 13.2269 12.9166 12.6496 12.3701
 12.0228 11.5448 11.0923 10.7910 10.6764 10.4101 10.3585  9.9016  9.8148  9.4819
  9.2506  9.1210  8.7173  8.6526  8.4961  8.1170  7.7748  7.5424  6.9273  6.8080
  6.2009  5.6831  5.0017  4.4674  3.7713  2.9574  2.4476  1.9691  1.3759  0.8818
  0.6400  0.6400  0.6400
 17.8735 17.6320 17.4084 17.1786 16.9223 16.6361 16.2390 15.8532 15.5317 15.2270
 14.9726 14.7182 14.4639 14.1765 13.8553 13.4639 13.0724 12.7422 12.4753 12.2083
 11.8244 11.5183 11.0874 10.9693 10.3147 10.3180 10.2337 10.0296  9.6704  9.5412
  9.3304  8.9854  8.7941  8.5154  8.3952  8.0274  7.7858  7.3618  7.0744  6.5947
  6.2534  5.4282  5.0103  4.4061  3.5952  2.8643  2.2063  1.7610  1.2669  0.7728
  0.6400  0.6400  0.6400
 17.9143 17.6802 17.4390 17.1826 16.9263 16.6457 16.2486 15.8515 15.4544 15.1614
 14.9013 14.6412 14.3811 14.1086 13.7055 13.3094 12.9180 12.5679 12.3009 11.8453
 11.7521 11.3491 11.0092 10.8806 10.6651 10.4443 10.0064  9.8200  9.5652  9.4603
  9.1033  8.8021  8.8039  8.3929  8.2766  7.9787  7.5976  7.3262  6.9120  6.6146
  6.0619  5.5081  4.8664  4.1354  3.4224  2.6534  2.1461  1.6519  1.1578  0.6637
  0.6400  0.6400  0.6400
 17.9663 17.6959 17.4407 17.1867 16.9304 16.6553 16.2582 15.8635 15.5177 15.1553
 14.8025 14.5424 14.2823 13.9758 13.5728 13.1698 12.7667 12.3935 11.8662 11.2459
 11.6596 11.3985 10.8634 10.7462 10.5456 10.2204  9.9978  9.9167  9.4172  9.3615
  8.9976  8.8395  8.6251  8.3809  8.0959  8.0313  7.6854  7.3531  6.8687  6.6196
  6.0211  5.5151  4.6782  4.1240  3.2644  2.5240  2.0410  1.5429  1.0488  0.6400
  0.6400  0.6400  0.6400
 17.9640 17.6947 17.4410 17.1872 16.9334 16.6649 16.2962 15.9504 15.6046 15.2460
 14.8710 14.4960 14.1835 13.8431 13.4401 13.0731 12.7211 12.2679 12.0667 11.4705
 11.5210 10.9378 10.5820 10.5504 10.3108 10.1297 10.0025  9.6549  9.3823  9.2771
  9.0647  8.6888  8.5083  8.2821  8.1340  7.8393  7.5550  7.1746  6.7947  6.3021
  5.7495  5.1866  4.5709  3.9764  2.9968  2.8497  2.0111  1.4338  0.9397  0.6400
  0.6400  0.6400  0.6400
```

Appendix C Sample Incident Wave Spectrum File

The input two-dimensional spectrum required to run STWAVE is specified in the `spec.in` file. A description of the file and formatting is given in Chapter 3 of the main text. An example of a file header and the energy densities (meters squared/hertz/radian) in the first five frequencies (0.0312 to 0.0624 Hz, with 35 direction bins per frequency) of the spectrum for Ponce de Leon Inlet, Florida (see Example 1 in Chapter 6 – main text) are given below:

```
30  35
 0.0312 0.0390 0.0468 0.0546 0.0624 0.0702 0.0780 0.0858 0.0936 0.1014
 0.1092 0.1170 0.1248 0.1326 0.1404 0.1482 0.1560 0.1638 0.1716 0.1794
 0.1872 0.1950 0.2028 0.2106 0.2184 0.2262 0.2340 0.2418 0.2496 0.2574
    96031202  0.  0.    7.81200E-02   0.340000
   0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
   0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
   0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
   0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
   0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

   0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
   0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
   0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
   0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
   0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

   0.00000  0.00000  0.00000  0.00000  0.00001  0.00003  0.00011
   0.00033  0.00082  0.00174  0.00326  0.00543  0.00810  0.01092
   0.01336  0.01488  0.01513  0.01404  0.01187  0.00912  0.00634
   0.00397  0.00222  0.00109  0.00046  0.00017  0.00005  0.00001
   0.00000  0.00000  0.00000  0.00000  0.00000  0.00000  0.00000

   0.00000  0.00000  0.00001  0.00006  0.00039  0.00182  0.00661
   0.01951  0.04837  0.10330  0.19343  0.32176  0.48009  0.64709
   0.79177  0.88232  0.89697  0.83206  0.70350  0.54069  0.37614
   0.23537  0.13135  0.06460  0.02756  0.00998  0.00297  0.00070
   0.00012  0.00001  0.00000  0.00000  0.00000  0.00000  0.00000

   0.00000  0.00000  0.00003  0.00036  0.00238  0.01123  0.04081
   0.12041  0.29856  0.63764  1.19397  1.98611  2.96345  3.99427
   4.88737  5.44632  5.53671  5.13607  4.34248  3.33753  2.32181
   1.45289  0.81075  0.39874  0.17010  0.06158  0.01835  0.00431
   0.00075  0.00009  0.00001  0.00000  0.00000  0.00000  0.00000
```

Appendix D
Sample Current Field File

The input current field required to run STWAVE is specified in the `current.in` file. A description of the file and formatting is given in Chap-ter 3 of the main text. An example of the first row (J = NJ) of the currrent file for Ponce de Leon Inlet, Florida (see Example 1 in Chapter 6 – main text) is given below (*u* and *v* velocity components in meters/second):

```
53 112  50.0
96031202
 -5.9655029E-03  6.6245958E-02 -5.6242347E-03  6.6273674E-02 -5.2828006E-03
  6.6299401E-02 -4.9415343E-03  6.6327110E-02 -4.6002306E-03  6.6354163E-02
 -4.2588841E-03  6.6381201E-02 -4.0070452E-03  6.6551067E-02 -3.7839543E-03
  6.6767417E-02 -3.1688120E-03  6.6419885E-02 -2.4407078E-03  6.5910846E-02
 -1.7125718E-03  6.5401770E-02 -9.8446012E-04  6.4892732E-02 -2.5634654E-04
  6.4384326E-02  4.7177821E-04  6.3874617E-02  1.1998974E-03  6.3366205E-02
  1.6661584E-03  6.2946498E-02  1.9737110E-03  6.2570527E-02  2.2812057E-03
  6.2195450E-02  2.5883764E-03  6.1821289E-02  2.8955825E-03  6.1447740E-02
  3.2027178E-03  6.1072327E-02  3.4305919E-03  6.0723398E-02  3.6268979E-03
  6.0384035E-02  3.8230885E-03  6.0042873E-02  4.0193945E-03  5.9703503E-02
  4.2156633E-03  5.9363544E-02  4.8182383E-03  5.8781888E-02  5.4505821E-03
  5.8182545E-02  6.0829669E-03  5.7583157E-02  6.7153089E-03  5.6983806E-02
  7.3386896E-03  5.6374207E-02  7.8893714E-03  5.5682164E-02  8.3813462E-03
  5.4892469E-02  8.4857941E-03  5.3458244E-02  8.5342079E-03  5.1979322E-02
  8.3248559E-03  5.0295375E-02  8.1154760E-03  4.8611302E-02  7.9061203E-03
  4.6927348E-02  7.6967701E-03  4.5243401E-02  7.4873865E-03  4.3559320E-02
  7.1142977E-03  4.0876567E-02  6.7089610E-03  3.7997276E-02  6.3036624E-03
  3.5118129E-02  5.8720950E-03  3.2525599E-02  5.3928681E-03  3.0454256E-02
  5.0333366E-03  2.8710742E-02  4.7800979E-03  2.7258173E-02  4.5269663E-03
  2.5806203E-02  4.2738337E-03  2.4354232E-02  4.0205559E-03  2.2901440E-02
  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
  0.0000000E+00
```

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This report describes application of the steady-state spectra wave model STWAVE. The purpose of STWAVE is to provide an easy-to-apply, flexible, and robust model for nearshore wind-wave growth and propagation. Recent upgrades to the model include wave-current interaction and steepness-induced wave breaking. STWAVE has also been incorporated into the Surface-Water Modeling System, which provides a user interface and supporting software for grid generation, interpolation of current fields, generation of input spectra, and visualization of model output.

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